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Air Force flightline fire incidents are characterized by a bimodal distribution; small fires constitute 95% of the database and are considered sensitive to both effectiveness and collateral damage potential of the extinguishing agent. Large fires are relatively infrequent and are less sensitive to collateral damage. The Air Force also experiences approximately 600 "unreported" agent discharges each year. The agent most frequently used for small and unreported incidents is Halon 1211. A relatively low loss rate of $12.2K per incident is attributable to minimal collateral damage associated with the use of Halon 1211. The high frequency of these incidents indicates that conversion to a potentially contaminating agent such as dry chemical can have a significant adverse impact on aircraft "out of service" and repair costs. The annual costs associated with engine repairs due to collateral damage could be as high as $40.5 M. This assumes an annual frequency of 162 incidents involving contamination of aircraft

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PREFACE

This report was prepared by the Naval Research laboratory, Code 6180, Washington, DC and its contractor, Hughes Associates, Inc., 6770 Oak Hail Lane, Suite 125, Columbia, MD 21045-4731. The work, completed in April 1993, was performed under NRL Contract 2330-G47.

The report describes the results of a statistical study of Air Force flightline fire incidents and extinguishing agent discharges over approximately a ten-year period. Evaluation of both Navy Safety Center fire incident reports and air base responses to inquiries regarding unreported extinguishing agent discharges provided a basis for (1) estimating the usage/demand of Halon 1211 on the flightline and (2) projecting the potential impact of reported and unreported alternative agent discharges on aircraft fire damage and component contamination costs (i.e., collateral damage potential).

The authors wish to acknowledge the technical support and information exchange provided by Mr. Robert Galindo, ARA Inc., Tyndall Air Force Base, FL.

The work was performed between September 1992 and April 1993. The WL/FIVC project officer was Mr. Charles W. Risinger.

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EXECUTIVE SUMMARY

A. *OBJECTIVE*

The objective of this study was to provide detailed background information in support of strategy development regarding the continued use or replacement of Halon 1211 as a fire extinguishing agent for use on USAF flightlines.

B. BACKGROUND

Due to its potential adverse impact on the environment, the phase out and replacement of Halon 1211 as a primary flightline fire extinguishing agent is under consideration by the Air Force. Candidate solutions include development of a replacement agent having similar fire fighting characteristics or conversion to an existing agent such as dry chemical (PKP). Procurement and analysis of flightline fire incident data and unreported extinguishing agent discharge frequencies were necessary in order to rationally select the most effective strategy for replacement of Halon 1211.

In response to this need, a study was initiated at the Naval Research Laboratory at the request of the Air Force (WL/FIVCF) to identify, collect, and evaluate available data on flightline fire incidents and extinguishing agent discharges. It was intended that this study provide a statistical assessment of fire frequency, agent discharge frequency, and the potential impact of contaminant agents on aircraft collateral damage.

C. SCOPE

The study included (1) a detailed review of available flightline fire incident reports, (2) air base surveys of unreported fire frequency and incidental agent discharge frequency, (3) review of the technical literature and military fire fighting doctrines regarding extinguishment agent usage and effectiveness, and (4) projections of the annual costs associated with collateral damage from the use of potentially contaminating extinguishing agents. A detailed life cycle cost analysis was considered beyond the scope of this effort. However, upper bound estimates were developed for the potential repair and maintenance costs associated with the use of a contaminating agent for the fires where it was determined that aircraft engine contamination was highly likely. In addition, detailed records were not available for much of the information sought for this study. While this occurred, it was necessary to approximate or extrapolate the history.

The report documents the results of the incident analysis and the field inquiries, and provides an analysis of these data in terms of the types and frequencies of flightline fires and the magnitude of unreported extinguishing agent discharges. Estimates of the annual magnitude and costs of collateral damage due to aircraft engine contamination are provided. Based on these analyses, conclusions are provided regarding the potential impact of replacing Halon 1211. In addition, it is recommended that a more board-based benefit/cost analysis be conducted to evaluate specific alternative strategies.

D. METHODOLOGY

This study incorporates a technical literature review and engineering analysis of extinguishing agent technologies as well as military applications, standard statistical analyses of flightline fire incident reports, and the design of field surveys to obtain representative information currently not centrally collected and maintained by the Air Force. Recognized methods of statistical analysis were employed.

E. TEST METHOD DESCRIPTION

A commercial database management program (Paradox 3.0) was used to create the fire incident database from the Navy Safety Center fire management reports. Key parameters were included in the design of the database in order to analyze the incident data relative to the scope of this effort. This database program readily accepted statistical analyses of the incident data.

F. RESULTS

Air Force flightline fire incidents are characterized by a bimodal distribution; small fires constitute 95 percent of the database and are considered sensitive to both effectiveness and collateral damage potential to the extinguishing agent. Large fires are relatively infrequent and are less sensitive to collateral damage. The Air Force also experiences approximately 600 "unreported" agent discharges each year. The agent most frequently used for small and unreported incidents is Halon 1211. A relatively low loss rate of $12.2K per incident is attributable to minimal collateral damage associated with the use of Halon 1211. The high frequency of these incidents indicates that conversion to a potentially contaminating agent such as dry chemical can have a significant adverse impact on aircraft "out of service" and repair costs. The annual costs associated with engine repairs due to collateral damage could be as high as $40.5M. This assumes an annual frequency of 162 incidents involving contamination of aircraft engines and an average repair cost of $250,000.

G. CONCLUSIONS/RECOMMENDATIONS

The limited scope of this study indicates that replacement strategies for Halon 1211 for flightline fire fighting should be developed based on extinguishment effectiveness and collateral damage potential associated with the predominant "small" fire scenarios. Refinement of candidate strategies will require a broad-based benefit/cost analysis utilizing a quantitative technique such as Decision Analysis.

It is also recommended that the Air Force modify its incident and maintenance reporting system(s) to permit tracking of cases through the system on a routine basis. A potential approach to such an effort would be identification and tracking of several case studies in order to identify optimum procedures and data entry requirements to enable tracking of damage and maintenance/repair costs and correlating such data with appropriate casual factors.

H. BENEFITS

The results of this study provide discrete historical information regarding the frequency and types of flightline fire incidents and extinguishing agent discharges. This information provides the Air Force with necessary input to identify candidate strategies for replacement of Halon 1211 and the potential impact to Air Force flightline operations.

I. TRANSPORTATION OF TECHNOLOGY

This information, along with the database design and approach, could potentially be used by the commercial airport industry to assist in similar decision making regarding replacement of Halon 1211.

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SECTION I
INTRODUCTION

A. OBJECTIVE

The Air Force uses several fire fighting agents on the flightline, including Halon 1211, CO_2, PKP, water and AFFF. In recent years (i.e., after 1983) the predominant agent used to suppress small incidental flightline fires has been Halon 1211. This predominant use of Halon 1211 for small fires has been attributed to its suppression capabilities and its minimal effects on aircraft components (i.e., secondary or collateral damage). Other available agents such as PKP or water can result in greater damage to the aircraft than that resulting from the initial fire, requiring that the aircraft be removed from service for maintenance or overhaul of sensitive components.

Due to the potential adverse effects of Halon 1211 on the earth's ozone layer (Reference 1), the need to develop an alternative for Halon 1211 has become a priority. Consideration is also being given to adaptation of other existing fire-suppression agents for flightline fire fighting. The objective of this study was to provide background information in support of this decision process.

B. BACKGROUND

1. General

The Air Force has a variety of fire fighting agents available for suppressing fires on the flightline. These agents include Halon 1211, carbon dioxide (CO_2), Aqueous Film Forming Foam (AFFF), water and dry chemical (PKP). All of these fire suppression agents are potentially effective on fires involving flammable and combustible materials found on the flightline.

Currently, Halon 1211 is the Air Force's agent of choice for fighting aircraft and other associated fires on the flightline. Halon 1211 offers a number of advantages over other fire suppression agents. For example, it is a "clean" agent which does not leave a residue when applied. This minimizes secondary damage to high value components of jet aircraft. Second, Halon 1211 discharges as a liquid, allowing the agent to penetrate into the fire from a safe distance. Third, since the agent converts from a liquid to a gas when discharged, it can also penetrate into enclosed spaces such as engines, nacelles and electronic equipment cabinets and consoles.

Halon 1211 is a man-made chemical that depletes the stratospheric ozone layer which acts as a shield against harmful solar ultraviolet (UV) radiation. During the mid 1970's, chlorine had been suspected of destroying stratospheric ozone. Further research has indicated that the bromine and chlorine from halons are also having an adverse effect on the ozone layer (Reference 1).

Although the use of CFCs was banned in nonessential aerosol products in the late 1970s, their production continued to increase. This prompted the United Nations to develop an international framework to protect the stratospheric ozone. This was known as the 1985 Vienna Convention to protect the ozone layer. This eventually lead to the adoption of an international treaty called the Montreal Protocol on Substances that Deplete the Ozone Layer. By 1987, the treaty had been signed by 24 nations, including the United States. Other nations have since signed the treaty.

The Montreal Protocol required that production of Halon 1211 be frozen in 1992 to 1986 production levels. However, subsequent scientific evidence has indicated that the ozone depletion was far more extensive than had been predicted. Therefore, the United States Government called for a phase-out of halon by the year 2000. To date, over 90 nations have signed the nonbinding Helsinki Declaration calling for a complete phase-out of halons as soon as feasible. In all probability, the phase out period for halons will be reduced considerably in the upcoming months.

The U.S. Department of Defense has developed various initiatives on the use of halon under this jurisdiction. Initial strategies included a ban on atmospheric releases for training, discharge testing, and purchase of new halon extinguishers. The military categorized halon fire protection applications as either mission-critical, essential, or non-essential. The mission-critical uses are scheduled to continue beyond the year 2000 and include protection of aircraft engines, nacelles, cargo bays, fuel cells, cockpits, and electronic bays; ship machinery rooms, fuel storage areas, critical electronic spaces, engine rooms, tanks, and armored personnel carrier crew spaces (Reference 2).

2. Annual Halon 1211 Usage Estimates and Future Cost Penalties

In order to comply with Department of Defense directives toward compliance with the Montreal Protocol, the Department of the Navy has initiated annual surveys on the procurement and use of Halon 1211, as well as other chlorofluorocarbons (CFCs). The intent of these surveys is to provide a basis for development of a strategy for future mission essential halon reserve requirements for the Navy and Marine Corp.

Table 1 provides a summary of Halon 1211 procurement and usage estimates based on responses to the Department of the Navy survey (Reference 3). Estimates of quantities of Halon 1211 available include extinguishers, systems and reserves. Discharge data was reported for fires, training, scheduled maintenance, system failure, accidental and other.

The total amount of Halon available within the Navy and Marine Corps during 1990 was approximately 1.8 million pounds. More than 1.5 million pounds was installed in active systems and approximately 300,000 pounds were held in reserve. The majority of Halon 1211 used (40 percent) during 1990 was for training. Other uses included fires (25 percent),

accidental (7 percent), system failure (11 percent), maintenance (12 percent) and other (7 percent). Over 300,000 pounds of Halon 1211 were procured during 1990.

A reasonable estimate of the quantities of Halon 1211 used on the Navy and Marine Corp flightlines are listed under "Aviation" application. Of the 75,610 pounds discharged in 1990 for Aviation use, 22,602 pounds were discharged due to fire incidents. This constituted nearly half of the fire-related discharges, illustrating the significant role of Halon 1211 on flightline fire fighting in the Navy and Marine Corp. Estimates of flightline fire related discharge amounts of Halon 1211 for the Air Force are similar, at 21,000 pounds in 1990 and 19,000 pounds in 1991 (Reference 4).

Table 2 illustrates the increased tax imposed on procurement of halons as provided in U.S. Federal legislation passed in 1989. Based on the current annual procurement estimate of 300,000 pounds, the annual cost of the increased tax on Halon 1211 to the Navy and Marine Corp will exceed $4.4 million by the turn of the century. At that point production of Halon 1211 will be completely phased out.

TABLE 1. HALON 1211 USAGE (IN POUNDS) ESTIMATES FOR NAVY AND MARINE CORP FACILITIES (CY90)

Application	No. of Responses	Quantity Procured	Quantity Available		Quantity Discharged							
			Charged Extinguisher	Reserve Stock	Fire	Training	Sch. Maint.	Unsch Maint.	System Failure	Accidental	Other	
SHIP	37	8,081	6,418	2,855	2,677	101	575	200	1,175	300	0	5,028
AVIATION	101	126,755	817,832	100,765	22,604	35,403	1,462	2,493	5,954	3,104	4,590	75,610
SHORE FAC	257	168,054	148,352	757,308	22,111	39,306	4,273	1,084	5,497	6,915	8,320	87,506
TOTAL	395	302,890	972,602	860,928	47,392	74,810	6,310	3,777	12,626	10,320	12,910	168,144

TABLE 2. PROJECTED PROCUREMENT TAXES FOR HALON EXTINGUISHANTS

	Tax Per Pound	
Year	Halon 1301	Halon 1211
1993	$0.25	$0.25
1994	$26.50	$7.95
1995	$31.00	$9.30
1996	$35.50	$10.65
1997	$40.00	$12.00
1998	$44.50	$13.35
1999	$49.00	$14.70

3. Halon Replacements

Research into Halon 1211 replacements has been actively pursued for over 15 years. During this period, a "first generation" of halon replacements has been developed, as well as halon alternatives. Potential alternatives to halon include dry chemical, water mist, foams, inert gases, and other extinguishing agents including a combination of agents. This section provides a cursory review of the status of research into Halon 1211 replacement agents.

a. Evaluation Criteria for Replacement Agents

Several potential replacement streaming agents are currently being developed. Most of these agents are still in the research phase. Evaluation criteria for replacements relate to the boiling point of the agent, the required concentration for fire extinguishment, the expected ozone depletion potential (ODP), the toxicity, and the global warming potential (GWP).

The boiling point of the agent is important in the determination of the usefulness of the replacement agent for streaming (not total flooding) applications, an important consideration for replacement of Halon 1211. Agents with boiling points lower than -20°C are too gaseous to be used effectively in streaming applications.

The effectiveness of the agent is typically based on a comparison to Halon 1211 when tested in the 5/8-scale cup burner. Full-scale extinguishment testing of alternatives are not well documented. Halon replacement agents typically rely on one of the following mechanisms for extinguishing a fire:

(1) removal of fuel;
(2) removal of oxygen;
(3) cooling of fuel; or
(4) inhibiting the combustion chemical reaction.

Research has indicated that the presence of bromine or iodine contribute significantly to extinguishment by inhibiting the combustion chemical reaction. However, these elements also affect other evaluation criteria (e.g., toxicity, ODP) for the compounds. Halon 1211 typically extinguishes a fire by inhibiting the combustion chemical reaction. The most effective replacement agents use these extinguishing mechanisms also. Some replacement agents use physical extinguishing mechanisms (i.e., items 1-3 above).

The ozone-depletion potential (ODP) and global warming potential (GWP) of replacement agents are a function of the elements of the gas and the atmospheric lifetime of the compound when released. Brominated or chlorinated compounds have been demonstrated to increase ozone depletion.

The toxicity of the agents themselves, as well as gases created from exposure to fire, is also a matter of concern. For example, when Halon 1211 is applied to a fire, toxic byproducts such as hydrogen bromide and hydrogen fluoride may be produced. And some replacements have demonstrated a potential for producing toxic decomposition products. As agents are developed, further research into toxicity will be required.

b. Replacement Agents

Selected classes of compounds examined to date include the following:

(1) hydrobromofluorocarbons (HBFCs);
(2) chlorofluorocarbons (CFCs);
(3) hydrochlorofluorocarbons (HCFCs);
(4) perfluorocarbons (FCs); and
(5) hydrofluorocarbons (HFCs).

HBFCs are very effective extinguishing agents. They use a chemical extinguishing mechanism. However, HBFCs have a relatively high ODP. Examples of HBFC streaming agents include HBFC-22B1 (CHF_2Br) and HBFC-124B1 (CF_3CHBrF).

CFCs appeared very effective as extinguishing agents in initial studies. However, the ODP of these compounds was determined to be too high to warrant further research.

HCFCs are also effective extinguishing agents, but not as efficient as Halon 1211. The extinguishing mechanism for HCFCs is based on physical actions. The ODP, GWP, and toxicity HCFCs appear to be low, but are not zero. HCFC123 (CF_3CHCl_2) is an example of an HCFC streaming agent.

The current leading replacement candidates are FC and HFC compounds. HFCs and FCs rely on physical extinguishing mechanisms and are less effective extinguishing agents than Halon 1211. Examples of FCs and HFCs are FC-5-1-14 (C_6F_{14}) and HFC-227ea (CF_3CHFCF_3) respectively. Both compounds have ODPs of zero and very low toxicities. However, both have GWPs. The GWP of FCs is greater than HFCs.

A comparison of Halon 1211 with potential replacement agents is summarized in Table 3. Items reviewed include the boiling point, extinguishing coefficient, ODP, GWP, and toxicity.

The U.S. Air Force is sponsoring its own research and development of substitute agents for Halon 1211 for both training and general-purpose suppression. Several potential agents have been identified and are undergoing field testing. The field testing has included flammable and combustible liquid fires. These new agents have lower Ozone Depletion Potentials (ODPs) than Halon 1211 (Reference 5).

As part of this research, fluorocarbons have been targeted as potential halon alternatives because of their fire suppression effectiveness and cleanliness qualities. The hydrogen substitution provides a decreased ODP and GWP while fluorine substitution decreases the probability of hepatotoxicity. Therefore, agents with hydrogen and fluorine have been given top consideration. Initial work in the alternative agent area has identified over 650 potential compounds, with testing and evaluation being limited to several compounds possessing the most attractive characteristics relative to suppression capability, potential for atmospheric effects, adverse collateral effects, human toxicity and cost.

c. Potential Research Directions

FCs and HFCs are replacement agents with adequate extinguishing characteristics and low ODP and GWP. These agents are the primary replacement agents at this point. However, all of the agents discussed thus far either have a ODP or GWP greater than zero or are not as effective as Halon 1211. Acceptable levels of ODP and GWP, or toxic and corrosive effects, if any, have not been identified. Therefore, further research into replacement agents is ongoing.

TABLE 3. COMPARISON OF CHARACTERISTICS OF HALON 1211 AND CANDIDATE STREAMING REPLACEMENT AGENTS

Name	BP (°C)	Ext. Conc.	ODP	LC_{50}	GWP
Halon 1211	-4	3.2	~4	>13	
Hydrobromofluorocarbons HBFC-124B1 (CHF_2Br) HBFC-22B1 (CF_3CHBrF)	 8 -15	 3.6 3.9	 0.3-0.4 ~1.4	 11	
Chlorofluorocarbons (CFC)			too high		
Hydrochlorofluorocarbons (HCFC) HCFC-123 (CF_3CHCl_2)	24	6.3	0.02	3.2	
Perfluorocarbons (FC) FC-5-1-14 (C_6F_{14})	56	4.4	0.0	Very low toxicity	Yes
Hydrofluorocarbons (HFC) HFC-227ea (CF_3CHFCF_3)	-16.4	5.9	0.0	80	Yes, lower than FCs

BP	=	Boiling point.
Ext. Conc.	=	Extinguishing concentration based on extinguishing of n-heptane fire in a cup burner.
ODP	=	Ozone depletion potential.
LC_{50}	=	Acute toxicity of compound based on in-vivo values in four-hour rate studies. The lower the LC_{50}, the more toxic the compound.
GWP	=	Global warming potential.

Areas of research include mechanisms to decrease tropospheric lifetime of the compounds such as reactions of a carbon-carbon double bond with hydroxyl free radicals, photolysis, and rainout. Potential agents include bromoalkenes, iodides, hydrogen containing geminal dibromides, and polar substituent bromocarbons.

Other important factors in the evaluation of replacement agents not examined include costs and storage stability. As research on agents continues, all the evaluation criteria specified must be pursued. Therefore, research on potential "second-generation" replacement agents is several years from completion.

4. Approach

The primary objective of this effort was to assess the usage of Halon 1211 on flightline fire incidents. The approach included a technical literature review, analysis of Air Force and Navy flightline fire fighting doctrine, and inquiries to the U.S. commercial airline/aircraft industries. These tasks were directed at providing information on distribution of fire incident types, estimates of unreported fire incidents, the impact of agent type on maintenance and overhaul activities, and the impact of contaminating agents on aircraft maintenance and costs.

The information obtained during these efforts was complied as part of this report.

C. SCOPE

Several tasks were performed in support of this effort. Included were the following:

- A literature review of fire fighting agent effectiveness and review of Navy Doctrine for recommended fire fighting agents and practices;

- Inquiries of various government agencies and other organizations to obtain information on halon usage and repairs to damaged equipment;

- A review of Air Force and Navy flightline fire incident experience to determine the frequency and severity of fires, as well as the extinguishing agents used; and

- Field surveys of the Air Force and Navy maintenance facilities and base fire departments to obtain information on aircraft engine maintenance and frequency of unreported fire fighting agent discharges.

SECTION II
INQUIRIES

Inquiries were made to various military, Federal Government, local authorities, and manufacturers in an attempt to determine the types of extinguishment agents used, policies/procedures regarding decontamination and maintenance of aircraft, and associated costs. Specific organizations contacted included the following:

(1) Navy Safety Center;
(2) Air Force and Navy maintenance depots;
(3) Air Force and Navy air base fire departments;
(4) Federal Aviation Administration;
(5) Commercial airport authorities;
(6) Aircraft manufacturers;
(7) Aircraft engine manufacturers;
(8) Extinguishing agent manufacturers; and
(9) AFCESA/RACF, Tyndall Air Force Base

Areas of inquiry included the following:
(1) Extinguishing agent selection/usage;
(2) Aircraft contamination records; and
(3) Associated maintenance and costs.

In terms of agent usage, requested information included the frequency of fire-related and accidental discharges, the types of agents used, and their general effectiveness. Specific requests associated with contamination records included documentation of mechanical and corrosive effects associated with the application of extinguishing agents, the frequency of contamination for each category of agent, and procedures related to aircraft repairs. Maintenance information requests targeted frequency, the logistical process, and cost estimates.

Results based on inquiries to the Navy Safety Center, Air Force and Navy maintenance depots, and air base fire departments are presented later in this report. Adequate data bases were obtained on Air Force and Navy flightline fire experience as well as estimates on "unreported" incidents involving agent discharge to complete a preliminary analysis of flightline agent usage experience over several years.

Statistical information regarding aircraft contamination and maintenance frequency and costs were not available. Most of this type of information obtained was anecdotal, with no common basis for compilation or analysis.

Organizations associated with the commercial airline industry were also contacted. These organizations included regulators, manufacturers, airport authorities and airport fire departments. It appears from the limited number of responses received, that many of these organizations will continue using Halon 1211 until alternative agents are developed and marketed. However, some

groups have modified their usage of halon for fire fighting while they await new fire fighting agents. The following is a sample of the responses received.

(1) Commercial Airport Authorities
Policies regarding "agent of choice" varied among several airport authorities. The Dallas, Fort Worth authority requires the use of Halon 1211 for aircraft engine and external incidental fires as the standard agent. The firefighters are instructed not to use PKP, CO2 or AFFF for such applications (contacts: Dallas-Fort Worth, Washington National, Baltimore-Washington, Tampa International).

(2) Federal Aviation Administration
The FAA has not mandated the use of one fire fighting agent over another. However, the FAA's preference is Halon 1211. It was indicated that many airport crash/rescue vehicles are set up to use PKP. They are basically waiting for the development of new substitute agents to replace halon (contact: FAA, Atlantic City, NJ).

(3) Canadian Ministry of Transport (CMT)
The CMT has placed a total ban on the use of halons for fire fighting purposes, and is currently relying on alternative agents, including AFFF and PKP (contact: CMT).

(4) Aircraft and aircraft engine manufacturers were neutral regarding selection of a particular extinguishing agent. In addition, none of the manufacturers contacted maintained records or maintenance activities related to decontamination of aircraft engines or other components due to extinguishing agent exposure (contacts: McDonnell-Douglas, Lockheed, General Electric, Pratt & Whitney).

(5) A commercial manufacturer of PKP indicated that contamination effects are primarily limited to moderate-term corrosion. Engines or electronics components exposed to PKP would require cleaning to prevent corrosion. The manufacturer does not provide specific guidance regarding contamination procedures (contact: Ansul Corporation).

(6) Navy's total cost (including squadron expenses, local maintenance, shipment and NAD costs) to clean and repair an aircraft engine contaminated by PKP is approximately 1/2 of the replacement cost of the engine (contact: NAS Oceana, VA).

(7) A precise estimate of aircraft engine maintenance and repair due to contamination involves detailed cost data for several factors, including the following (1) shipment, (2) type of engine, (3) component replacement costs, (4) fire damage, (5) extinguishing agent collateral damage, and (6) local maintenance costs (contact: AFCESA/RACF).

(8) Air Force frequency of unreported incidents involving extinguishing agent discharge is estimated to be three or four incidents/air base/year (contact: AFCESA/RACF).

SECTION III
FLIGHTLINE FIRE FIGHTING AGENTS

A. AGENT CHARACTERISTICS, APPLICATIONS AND LIMITATIONS

The Air Force and Navy have five common flightline fire-extinguishing agents:

(1) Halon 1211;
(2) Carbon dioxide (CO2);
(3) Dry chemical (PKP);
(4) Aqueous Film Forming Foam (AFFF); and
(5) Water.

The use of these agents to extinguish fires is recommended, based on the characteristics and limitations of the agents. These characteristics and limitations are established as a result of the extinguishing methods and secondary effects of the use of the agent. There are basically four methods of fire extinguishment (Reference 6):

(1) Physically separating the combustible substance from the flame;
(2) Removing or diluting the oxygen supply;
(3) Reducing the temperature of the combustible or the flame; and
(4) Introducing chemicals that modify the combustion chemistry.

A discussion of the agent characteristics, specific extinguishing mechanisms, type of fires for effective use and potential secondary impact of the use of each agent (e.g., damage or life safety related) is provided in Sections 3.1.1 through 3.1.5.

1. Halon 1211

Halon 1211 is a "clean" agent, is nonconductive, leaves no residue, and does not have any significant corrosive effects. It is stored as a pressurized liquid and discharged as a liquid stream; therefore, it has a greater discharge range than most gaseous agents (up to 30 feet) (Reference 7).

Halon 1211 extinguishes fires by causing a chemical reaction that interferes with the combustion chemistry. The agent is effective on Class A, B and C fires. Once exposed to the atmosphere, Halon 1211 begins to evaporate, permitting the agent to penetrate and spread to extinguish two and three dimensional fires. As a denser than air gas, Halon 1211 is also effective in extinguishing fires in shielded locations.

Halon 1211 is typically effective at concentrations as low as 2 to 4 percent. Reignition of the fire is a potential concern if effective concentrations are not maintained. However, this concern is not as great as with gases requiring higher concentrations for effectiveness (e.g., carbon dioxide).

There are potential toxic and irritant effects due to exposure to Halon 1211. However, these effects are considered negligible for most flightline applications. There is also a limited possibility of thermal shock to engines or other temperature sensitive equipment. This potential for thermal shock is not well documented.

2. Carbon Dioxide

Carbon dioxide is a nonconductive, nonreactive, colorless, and odorless substance that does not leave a residue (i.e. a "clean agent"). CO2 is stored in a pressurized vessel as a liquid and when discharged immediately vaporizes. Application of the agent as a gas limits the range of effectiveness of the agent to small (three to eight feet) distances (Reference 7).

CO2 extinguishes fires by the following mechanisms:

(1) reducing the oxygen content of the atmosphere to a point where combustion is not supported; and
(2) by cooling of the burning material.

Carbon dioxide is effective on surface Class A fires and Class B and C fires. Carbon dioxide is not effective on deep seated Class A fires or shielded fires in unenclosed spaces.

The use of carbon dioxide in some situations is a concern in that a very cold gas is discharged. Dry ice particles produced during the discharge of the extinguisher can carry a static electricity charge. This charge is potentially dangerous in explosive atmospheres as well as potentially damaging to electronics. In addition, thermal shock to engines or other temperature sensitive equipment is a possibility. This potential for thermal shock is not well documented.

In most cases for carbon dioxide to be effective, a minimum atmospheric concentration of approximately 30 to 60 percent is required (Reference 8). These relatively high concentrations are not only hazardous to personnel, but may be difficult to maintain in flightline applications. Therefore, the potential for reignition is relatively high.

3. Dry Chemical (PKP)

PKP is a nonconductive powder mixture consisting mainly of potassium bicarbonate. When applied to a fire, it leaves a heavy residue and is slightly corrosive. PKP has a range of stream reach of up to 45 feet (Reference 7).

The mechanisms of extinguishment for the agent include the following: (1) chemical reaction to inhibit combustion; (2) smothering action of products released (e.g., carbon dioxide and water) by PKP interaction with the fire; (3) radiation shielding provided by the dry chemical cloud caused by discharge, protection of the fuel from exposure to the flame; and (4) cooling of the fuel caused by heat absorption of the dry chemical agent.

PKP is a highly effective extinguishing agent for Class B fires, including two and three dimensional fires.

PKP does not provide a lasting inert atmosphere over the surface of flammable liquids; therefore the fuel is subject to reignition. Application of PKP to sensitive equipment will most likely result in damage. Exposure of occupants to PKP may cause temporary breathing difficulty, poor visibility or disorientation.

4. AFFF

AFFF is a non toxic water based foam extinguishing agent. The foam is a low viscosity, fast spreading and leveling substance. AFFF conducts electricity, and although it is not corrosive by itself or when diluted with fresh water, it can cause corrosion if mixed with seawater. It is compatible with PKP and Halon 1211 and has a normal use temperature range limited to 35-120°F. AFFF has an effective range of application of up to 30 feet.

AFFF foams extinguish fires by forming a barrier over the fuel which provides a smothering action and prevents or lowers fuel vaporization. In addition, AFFF cools the fuel substrate.

AFFF is a very effective extinguishing agent for flammable liquid pool fires and Class A fires. AFFF is effective on two- and three-dimensional fires and some shielded fires provided the foam or water can penetrate to access the area of combustion. If AFFF is applied to engine fires or energized electrical circuits, damage will most likely occur. In addition, if the surface of the AFFF is disturbed, reignition of the fuel is a potential.

5. Water

Water is a nontoxic substance that conducts electricity and is potentially corrosive (e.g., saltwater applications). Water has an effective application range of up to 35 feet.

Water extinguishes fires by smothering the fire with steam produced by the interaction of the water and heat, by cooling the fuel substrate and in some cases by emulsifying or diluting liquids.

Water is an effective extinguishing agent for Class A fires, and to a limited extent, on Class B fires. Water is effective on two- and three-dimensional fires and some shielded fires provided the water can penetrate to access the area of combustion.

If water is applied to engine fires or energized electrical circuits, damage will most likely occur. In addition, the application of water to flammable liquid fires potentially will spread the fire.

6. Summary

Table 4 summarizes the information presented in this section. Halon 1211 is the only agent which provides the flexibility of application to most fire scenarios of interest on the flightline, a discharge range of up to 30 feet, effectiveness at relatively low concentrations, does not leave a contaminant residue, and is not highly toxic.

B. NAVY FIRE FIGHTING DOCTRINE

The "NATOPS U.S. Navy Aircraft Fire Fighting and Rescue Manual" describes Navy fire fighting procedures and provides instructions for agent application (Reference 9). The criteria for recommended agent types and procedures are based on expected fire scenarios and agent effectiveness and limitations. Detailed criteria for primary agents and application procedures are specified. Two versions of NATOPS were reviewed. A March 1, 1980 version provided guidance for fire fighting prior to the use of Halon 1211. The October 1, 1989 version provided current criteria.

TABLE 4. SUMMARY OF EXTINGUISHMENT AGENTS PROPERTIES AND USES

Extinguishing Agent	Method of Extinguishment	Physical Properties	Uses/Limitations
Halon 1211	• Chemical reaction to inhibit combustion process	• No significant corrosive effects • "Clean" agent • Penetrates and spreads • Nonconductive • Potentially irritant and toxic; however, not likely in flightline applications	• Effective on Class A, B, and C fires • Discharged as a liquid, therefore effective from distance (up to 30 ft) • Effective at low (2-3%) concentrations; however, potential reignition is possible if concentration is reduced below effective level
PKP (dry chemical)	• Chemical reaction to inhibit combustion • Smothering action • Radiation shielding • Cools fuel source	• Nonconductive • Slightly corrosive • Very damaging to equipment	• Very effective on Class B fires • Not effective on deep seated fires • Effective on 3-D fires • Storage affected by water • Does not provide lasting, inert atmosphere; therefore, reignition is possible • Effective range up to 40 ft • Effective for quick knockdown and extinguishment of large flammable liquid fires
AFFF	• Excludes air • Halts fuel vaporization • Cools fuel substrate	• Low viscosity, fast spreading and leveling • Nontoxic and biodegradable • Conducts electricity • Corrosive (salt water)	• Effective against flammable liquid (Class B) fires • Effective on Class A fires • Compatible with PKP and halon • Normal use range of 35-120°F and up to 30 ft
CO_2	• Oxygen depletion • Cooling of fuel	• Nonreactive • Colorless • Odorless • Penetrates and spreads • Nonconductive • "Clean" agent	• Static electricity with discharge possibly resulting in shock hazard to personnel and ignition source • Potentially lethal to personnel • Effective on surface "Class A" fire • Cooling could damage engines • Effective on Class B and C fires • Range of effectiveness is limited to 3 to 8 ft • Concentrations for effectiveness are 30-60%; therefore, reignition is possible if high concentrations are not maintained
Water	• Cooling of fuel • Smothering with steam • Emulsifying or diluting liquids	• Conducts electricity • Damaging to energized circuits	• Effective on Class A fires

1. 1980 NATOPS Criteria

Fire fighting guidelines in the 1980 edition of NATOPS included recommendations for the application of multiple agents such as AFFF, carbon dioxide and PKP. The following are examples of the NATOPS specified primary fire fighting agents based on sample fire types:

	Fire Type	Primary Agent
(1)	Engine/tailpipe/nacelle fires:	CO_2
(2)	Cold start fires:	CO_2
(3)	Electrical/avionics equipment fires:	CO_2
(4)	Wheel/brake fires:	CO_2

All of the above fires usually develop initially as small controllable fires. As indicated in the table above, the primary agent in NATOPS (1980) for suppression of small potentially controllable fires in areas where a damage potential exists was carbon dioxide. Along with the recommendation for use, warnings about the limited application range, potential thermal shock, rapid dissipation and spark potential of CO_2 were also specified.

The NATOPS document recognized that PKP was a more effective extinguishing agent than carbon dioxide; however, because of the damage potential, Section 610 specified the use of carbon dioxide as the primary agent and to use PKP only:

"... when a fire in an aircraft cannot be extinguished with CO_2 the use of PKP to *prevent further damage outweighs the disadvantages."*

Warning about the ingestion of PKP into engines and accessory sections resulting in damage immediately follow Section 610. NATOPS (1980) indicated the required size and distribution of fire extinguisher also. Portable CO_2 (15 pound), PKP (30 pound) fire extinguishers, and wheeled cart extinguishers (50 pound CO_2 and 150 pound PKP) were required near each aircraft.

2. 1989 NATOPS Criteria

The 1989 criteria modified the recommended agent of application. The incorporation of Halon 1211 effected the doctrine, based on its versatility of application, effectiveness, and lack of limitations.

Fire fighting recommendations in 1989 still included multiple agents such as AFFF, carbon dioxide and PKP, but Halon 1211 was incorporated as a primary agent. The following are the primary fire fighting agents based on fire type as outlined in the 1989 edition of NATOPS:

	Fire Type	Primary Agent
(1)	Engine/tailpipe/nacelle fires:	Halon 1211 or CO_2
(2)	Cold start fires:	Halon 1211 or CO_2

(3) Electrical/avionics equipment fires: Halon 1211 or CO_2

(4) Wheel/brake fires: Halon 1211 or CO_2

Halon and CO_2 were chosen as primary agents, based on effectiveness in extinguishing the fire and the lack of contamination potential for most flightline fire-incident applications.

The current 1989 edition of NATOPS also recognizes that Halon 1211 is considerably more effective than carbon dioxide on Class B fires when compared on a weight of agent basis. As a result, 150 pound wheeled Halon 1211 extinguishers are required by Section 3.3.2 of NATOPS to be provided as the primary flightline extinguisher. The primary reasons for the superior performance of Halon 1211 include the following:

(1) Effectiveness greater than carbon dioxide;
(2) Effective at lower concentrations than most other gaseous agents;
(3) Application range of up to 30 feet;
(4) Potential for thermal shock is not as great as CO_2. Based on a heat of vaporization of 138 cal/g for carbon dioxide and 32 cal/g for Halon 1211 and that approximately twice the mass of CO_2 is required to extinguish a fire (Reference 10), Halon 1211 has approximately one-eighth the potential to cause thermal shock. (NOTE: The possibility of thermal shock using either agent is not well documented and requires further research.); and
(5) Carbon dioxide dissipates rapidly and has a spark potential.

Warnings are provided for the use of Halon 1211. These warnings include the potential for thermal shock and using self contained breathing apparatus in unventilated or confined spaces. The use of other agents is also discussed in NATOPS (1989). PKP and AFFF are both recognized for their effectiveness in particular situations. However, both have warnings regarding their use on engine or electrical fires based on the significant contamination potential.

A summary of NATOPS extinguishing agent criteria is provided in Table 5.

C. COMMON FLIGHTLINE FIRE SCENARIOS

An analysis of flightline incident data indicates that fires that have occurred can be separated into two categories; fires that have a small initial fire size (e.g., nacelle fires) and fires with a large or catastrophic initial fire size (e.g., fuel spills into debris). A large percentage of fire scenarios associated with aircraft are initially small. Table 6 indicates typical flightline fire scenarios and the potential initial fire size.

Extinguishing a small fire results in different fire fighting concerns than extinguishing large fires. For fires that start small, important considerations include speed of response, agent effectiveness and agent-induced damage potential. An effective agent should prevent the spread

of the fire and should not result in collateral damage. For large fires, the agent effectiveness, exposure protection, and speed of response are the critical criteria. Agent-induced damage is not a primary concern assuming that, in large fires, the object involved has already sustained serious damage.

TABLE 5. NATOPS EXTINGUISHING AGENT CRITERIA

Extinguishing Agent	Navy Doctrine	Warnings
Halon 1211	• Primary airfield extinguisher • Primarily for Class B and C fires • Discharge range of 10 to 30 feet • Recommended for electrical fires (or CO_2) • Recommended for tailpipe fires (or CO_2) • Recommended for internal engine fires (or CO_2)	• No vapor sealing; therefore, fuel is always subject to reignition • May cause thermal shock on an engine • In confined areas, operator should use breathing apparatus
PKP (dry chemical)	• Primarily for Class B fires • Effective for three-dimensional fires • Discharge range of 10 to 30 feet • Effective for mop-up of small fires in conjunction with AFFF	• No vapor sealing; therefore, fuel is always subject to reignition • Damaging to engines • May cause temporary breathing difficulty, poor visibility or disorientation
AFFF	• Superior extinguishing agent against fuel fires • Primary Class B fire fighting agent (1978) • Apply using variable stream fog nozzle	• May cause engine damage
CO_2	• Limited discharge range (3 to 8 feet) • Primarily for Class B and C fires • Recommended for fires including a. Accessory section, compression compartment and general engine compartment; b. Internal engine fires (or Halon 1211); c. electrical fires (or Halon 1211); and d. Tailpipe fires (or Halon 1211).	• No vapor sealing; therefore, fuel is always subject to reignition • CO_2 not permitted to inert atmosphere in electronic compartments • CO_2 prohibited to inert flammable atmospheres because of electrical charge • Thermal shock to engines may result • Exposure to high concentrations can be fatal
Water	• Not considered a suitable agent for large aircraft fuel fires without addition of foam agents or surfactants • Recommend fog or spray streams • Effective for a. Cooling ordnance or batteries; b. Extinguishing Class A fires; and c. Moving fuel from aircraft.	• Caution required to preclude disruption of AFFF blanket with water

TABLE 6. INITIAL FIRE SIZE POTENTIALS

Fire Scenario	Initial Fire Size Potential	
	Small	Large/Catastrophic
Non-aircraft	X	X
Engine/tailpipe/nacelle	X	
Cold-start	X	
Electronics/avionics	X	
Wheel/brake assembly	X	
Fuel spills/pool	X	X
Fuel leaks/3-D sprays	X	X
Exposures/debris	X	X

D. SUMMARY: AGENT EFFECTIVENESS VERSUS COLLATERAL DAMAGE POTENTIAL

Table 7 summarizes an evaluation of the effectiveness and collateral damage potential for five extinguishing agents commonly used in flightline fire fighting. The effectiveness and collateral damage potentials were assigned grades based on the effects on the eight flightline scenarios identified in the fire incident reports and the technical evaluation of the performance capabilities and limitations of each agent.

As previously discussed, both effective suppression and minimum collateral damage are crucial to mitigation of "small" fire incidents on the flightline. While effective suppression is also crucial for the "large" fire incidents, exposure protection is important and collateral damage effects are of lesser concern.

TABLE 7. AGENT EFFECTIVENESS VERSUS DAMAGE CONTROL

Fire Scenario	Agent Effectiveness/Damage Potential				
	Halon 1211	CO_2	Dry Chemical	Water (Fog)	AFFF
Non-aircraft	B/1	B/1	A/2	A/2	A/2
Engine/tailpipe/nacelle	A*/1	A*/2	A/4	C/3	A/3
Cold-start	A*/1	A*/1	A/3	C/3	A/3
Electronics/avionics	A*/2	A*/2	A/4	C/4	C/4
Wheel/brake assembly	A*/1	B/2	B/3	B*/3	B/3
Fuel spills/pools	B/1	B/1	B/1	C/1	A*/1
Fuel leaks/sprays	B/1	C/1	B/2	C/2	A/2
Exposures/debris	B/1	C/2	C/2	B*/1	A/1

* Primary Agent by NATOPS

Effectiveness:
A - Very effective
B - Moderately effective
C - Not Recommended

Collateral Damage Potential:
1 - None
2 - Minor
3 - Significant
4 - High

The information presented in Table 7 was evaluated, based on these requirements, resulting in a rank ordering of extinguishing agents based on fire size, fire type, and agent effectiveness and collateral damage potential. For "small" fires, the agents are ranked as follows:

(1) Halon 1211;
(2) CO_2;
(3) PKP;
(4) AFFF; and
(5) Water.

For large fire scenarios, the ranking is the following:

(1) AFFF;
(2) PKP;

(3) Water;
(4) Halon 1211; and
(5) CO_2.

The different ranking of agents, depending on whether or not the fire is small or large reflects qualitatively the effectiveness and damage potential of each agent for flightline fire fighting. Halon 1211 received the top ranking for small fires due to its effectiveness on the predominant flightline scenarios and its negligible collateral damage potential. However, under large-fire scenarios, the extended reach and cooling and shielding effects of AFFF, PKP, and water result in their higher ranking in spite of their increased collateral damage potential.

SECTION IV
FLIGHTLINE FIRE INCIDENT ANALYSIS

A. INCIDENT REPORTING SYSTEMS

A request was made to the Navy Safety Center (NSC) in Norfolk, Virginia for information related to flightline fire incidents for both the Air Force and the Navy. The NSC is the Department of Defense (DOD) repository for all DOD fire incident records. Incident reports were provided for the Air Force for the period from 1981 through September 1991. The reports associated with the Navy's flightline fire experience were for the period from 1977 through September 1991. Several of the years for both services, including 1991, appeared incomplete. The limited data records in the early years were attributed to changes in the reporting system and the fact that the Navy was using the system for several years before the Air Force. As a result, while the complete data base was used in evaluating trends in fire incidents and suppression agent usage, any direct comparisons between Air Force and Navy experience should be restricted to the 7-year period from 1984 to 1990, when both services reported all fire related incidents to the NSC.

Fire incidents reported to the NSC are documented in a standardized format, referred to as Fire Management Reports (FMR). The reports contain detailed information concerning the fire incident itself and base fire department response. These reports were provided by the NSC for a total of 895 flightline fire incidents. An example of an FMR is provided in Appendix A.

B. INCIDENT DATABASE

The FMR records contain a large amount of information. Review of the individual records revealed variations in the form of data entry, and the presence of information irrelevant to this effort. Therefore, in order to assure consistency in the records and to provide a straight forward means to analyze the data, the individual records were entered into a database management system. The database management program Paradox (Reference 11) was selected due to its versatility and IBM-PC compatibility.

The Incident Data Entry Form designed to transfer the FMR records to a Paradox database is presented in Appendix A. The form contained 15 fields of information, including fire incident type, fire size (involvement), type of extinguishing agent used, and estimated losses.

A review of the incident database revealed that several extinguishing agents are utilized in flightline fire fighting, including Halon 1211, CO_2, PKP, AFFF and water. In addition, the database included both nonaircraft (e.g., equipment) and aircraft incidents. Aircraft types ranged from small Cessna-type aircraft to the Air Force's largest cargo aircraft. The actual amount of extinguishing agent used for a particular incident varied considerably. For instance, FMR records indicated that anywhere from a few pounds to over 1000 pounds of Halon 1211 were used, depending on the circumstances. While the quantity of agent used is a valuable factor in

attempting to estimate the potential impact of an alternative agent on collateral damage, a correlation between amount of agent used and extent of damage could not be developed from this database.

In a significant number of the large fire incidents, more than one fire fighting agent was used to extinguish the fire. This was probably due to the size of the fire when fire fighting personnel arrived at the location of the incident. The need for large quantities of extinguishing agents thus led to more than one agent being used. Water and AFFF were the primary agents in cases where the aircraft was well involved in fire when the fire department arrived.

The FMRs provided limited general information on damage resulting from a fire incident. Usual'.', just the piece of equipment damaged or the equipment where the fire originated is identified. There are no requirements to report damage caused by the fire fighting effort. If for example, PKP was used to extinguish a wheel/brake fire and was ingested into the engine, the engine may have been removed from the aircraft, sent to a maintenance facility for a complete overhaul and then shipped back to the facility where it came from. This can amount to a significant indirect cost resulting from the original fire incident that is not trackable by the FMR records.

C. RESULTS

Tables 8 and 9 provide summaries of the 895 incident records for the Air Force and Navy, respectively. As the data show, gaps appear to exist in reporting. For instance, in reviewing Table 8 it is unrealistic to conclude that the Air Force only had one flightline incident in 1981, and no incidents in 1982 or 1983. In discussions with NSC personnel it was determined that this time period coincided with transfer of Air Force incident reports to the NSC, and the records would not be considered representative of the Air Force's actual experience.

A more detailed examination of the "reported" incident records involved separation of aircraft and non-aircraft incidents, the type of fire incident, the size of the fire and related losses, and the frequency of extinguishing agent usage. Detailed results are presented in Appendix B. The results are tabulated separately for the Air Force and Navy, and then combined for both services.

Analysis of the fire incident records indicates a bimodal distribution of reported incident size. Of the 895 reported incidents, those characterized by no fire (e.g., vehicle accident or equipment failure without an accompanying fire) or a small smoldering or flaming fire represented 95 percent of the incidents (see Fig. 1). The estimated average dollar loss associated with these incidents was $12,060 per incident. The remaining incidents involved large fires and extensive damage. The average loss per incident associated with this group of incidents was $1,405,337. Each of the 49 larger fire incidents involved a catastrophic incident (e.g., flightline crash) or considerable damage to one or more aircraft and support equipment. Under these conditions, the impact of the extinguishing agent used is considered irrelevant in terms of collateral damage.

The distribution of incidents based on the type of initiating fire is provided in Figure 2. About one-fourth of the reported incidents did not involve an aircraft. The most common aircraft fire scenario in the database involved the aircraft engine (21 percent). The frequency of fires involving cold starts, electronics and avionics, wheel and brake assemblies and fuel spills were essentially the same, and together accounted for approximately 45 percent of the reported incidents.

TABLE 8. U.S. AIR FORCE FLIGHTLINE FIRE INCIDENT DATA SUMMARY STATISTICS YEARLY TOTALS (1981-91) OF ALL INCIDENT TYPES

Year	No. of Incidents	Dollar Loss	Avg. Loss/ Incident	No. of Injuries	No. of Deaths
1981	1	69	69	0	0
1984	54	872,424	16,156	22	0
1985	96	5,125,416	53,390	17	0
1986	87	3,329,205	38,267	9	3
1987	81	27,642,325	341,263	34	1
1988	62	25,084,618	404,591	21	0
1989	52	4,113,481	79,105	15	2
1990	56	1,490,127	26,609	13	0
1991	26	776,364	29,680	13	0
Totals	515	68,434,029	132,882	144	6

* through September 1991

TABLE 9. U.S. NAVY FLIGHTLINE FIRE INCIDENT DATA SUMMARY STATISTICS YEARLY TOTALS (1977-91) OF ALL INCIDENT TYPES

Year	No. of Incidents	Dollar Loss	Avg. loss/ Incident	No. of Injuries	No. of Deaths
1977	1	2,627,600	2,627,600	6	0
1978	18	52,607	2,923	2	0
1979	15	23,314	1,554	1	0
1980	14	2,835,244	202,517	3	0
1981	12	19,445	1,620	1	0
1982	22	94,457	4,294	1	0
1983	13	109,794	8,446	0	0
1984	28	372,145	13,291	4	0
1985	62	1,361,823	21,965	0	0
1986	49	1,379,023	28,143	2	0
1987	54	273,394	5,063	3	0
1988	46	1,037,730	22,559	3	0
1989	19	293,413	15,443	2	1
1990	12	700	58	0	0
1991	15	149,780	9,985	3	0
Totals	380	10,630,469	27,975	31	1

* through September 1991

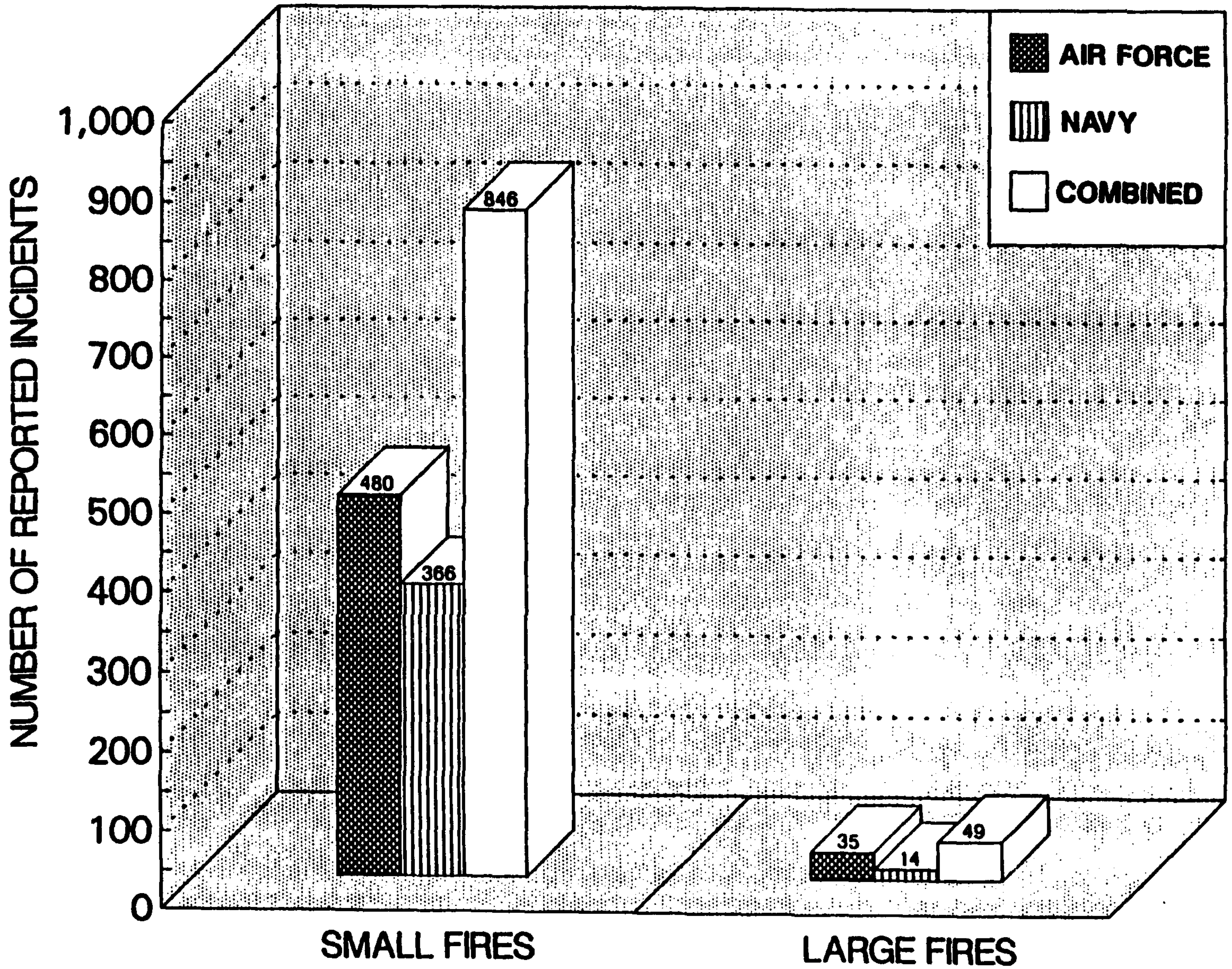

Figure 1. Distribution of reported small and large flightline fire incidents

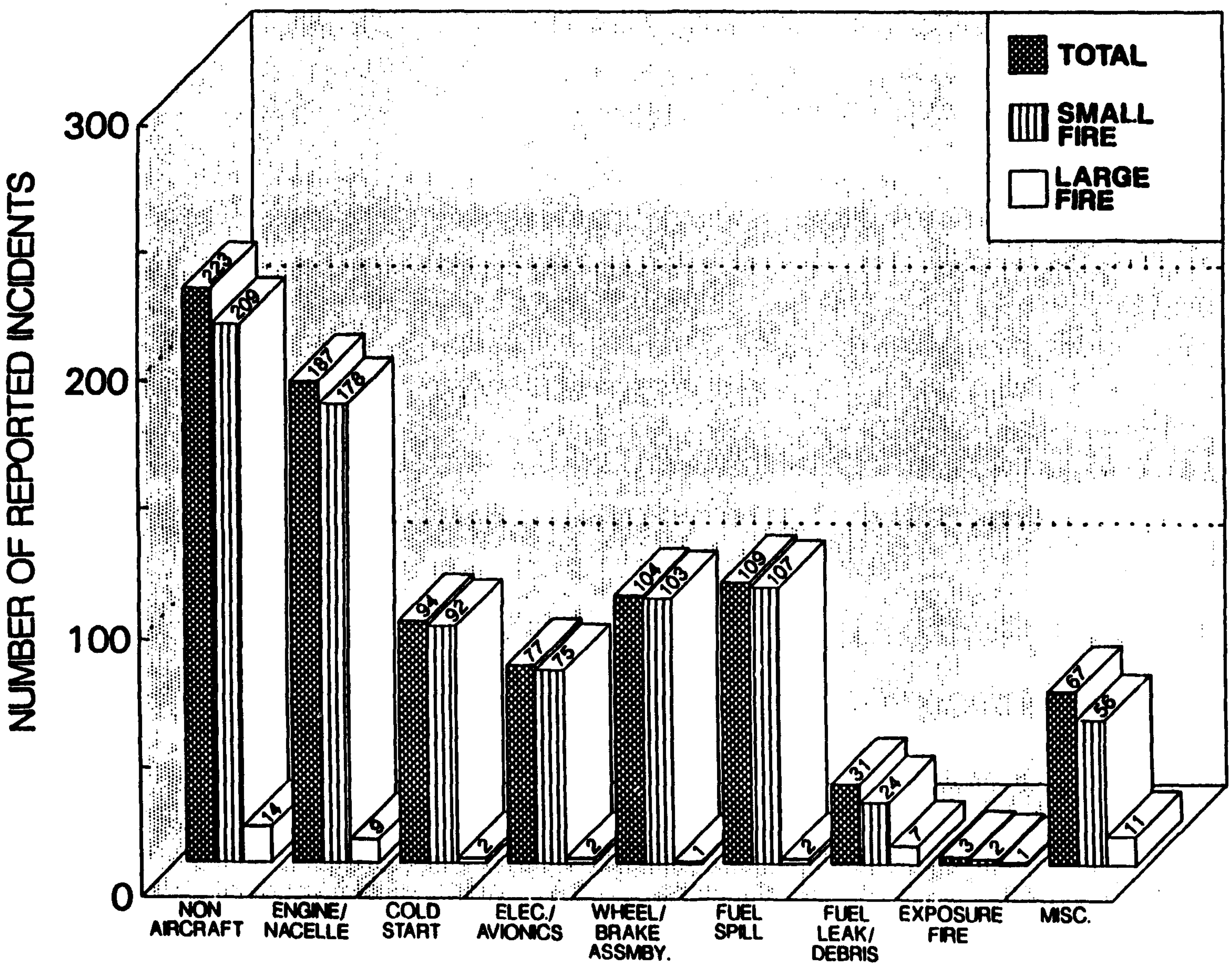

Figure 2. Distribution of reported small and large flightline fire incidents by incident type (Combined Services)

As illustrated in Figure 3, Halon 1211 is the predominant choice for reported flightline fire incidents, particularly for small incidents. AFFF and water were most frequently used in large fire incidents; the combined use frequency approaching two-thirds of the reported cases. This result would be expected. Under large fire conditions, the stream reach and cooling efficiency of water and AFFF are desirable characteristics. Potential collateral damage due to corrosion or residue accumulation would be considered of secondary importance under such extreme fire conditions.

PKP, which provides the greatest source for equipment contamination, was used as the primary extinguishing agent in only 5 percent of the reported small fire incidents.

To analyze the incident reports in terms of annual experience, it was necessary to select a subset of the records that represented reasonably complete reporting to the NSC. The time period which included consistent reporting for both the Air Force and the Navy was from 1984 to 1990. The year 1991 was not included because the reports included only the first nine months of the year.

The results of this part of the analysis are presented in Table 10. Nearly two-thirds of the incidents were reported by the Air Force during the 7-year period from 1984 to 1990. The frequency of small fire incidents remained the same as that for the total incident database at 95 percent. Estimated combined annual losses associated with the small incidents were $1,342,000 or $13,000 per incident. Annualized losses were slightly lower for the Air Force, at $12,243 per incident.

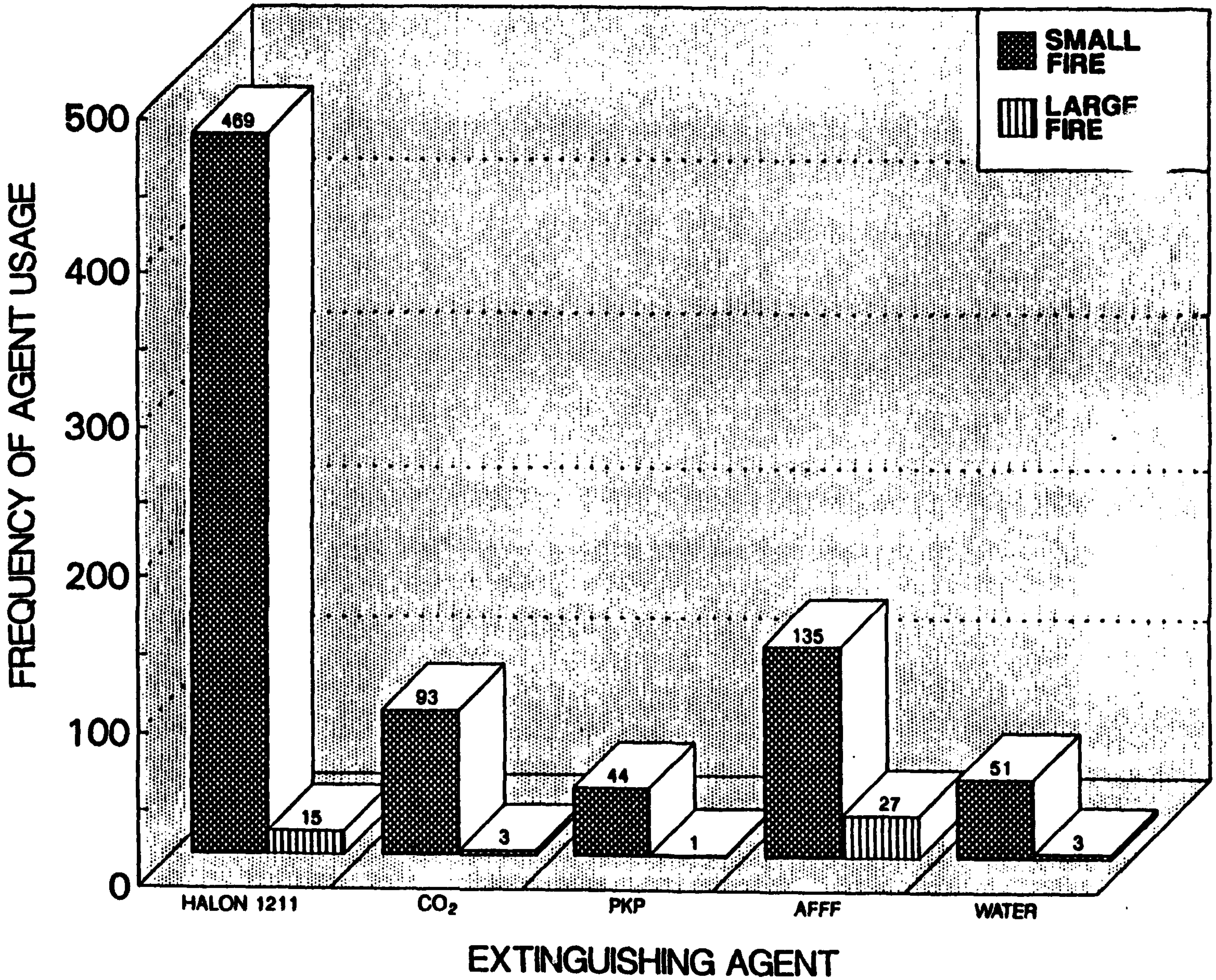

Figure 3. Frequency of extinguishing agent usage for small and large reported fire incidents (Combined Services)

TABLE 10. SUMMARY OF REPORTED N.S.C. FIRE INCIDENTS AND ESTIMATED LOSSES (1984-90)

Fire Type	Service	No. of Incidents	Estimated Losses ($K)	Loss Per Incident ($K)	Incidents Per Year	Annual Losses ($K)
All	Air Force	488	67,658	139	69.7	9,664
	Navy	270	4,718	17	38.6	671
	Combined	758	72,376	95.5	108.3	10,335
Small	Air Force	456	5,577	12.2	65.1	797
	Navy	265	3,820	14.4	37.9	546
	Combined	721	9,397	13	103	1,342
Large	Air Force	32	62,080	1,940	4.6	8,869
	Navy	5	898	180	0.7	128
	Combined	37	62,978	1,702	5.3	8,996

Thirty-two of the 37 large fires over the 7-year period (1984-90) were reported by the Air Force. Annualized losses associated with these fires were estimated at over $8.8 million.

SECTION V
FIELD SURVEYS/INQUIRIES

A. GENERAL

Analysis of flightline fire incident reports from the Navy Safety Center (NSC) database provided information regarding agent usage and frequency for selected flightline fire incidents. However, interviews with several base level fire department personnel revealed a lack of uniformity among the services and the individual bases regarding the criteria for incident reporting to the NSC. And, there is a significant number of flightline incidents involving suppression agent discharge which are not reported; e.g., incidents involving accidental agent discharge or incidents involving small fires which are readily extinguished with only minor fire damage. While these incidents are often considered insignificant in terms of "reportable" fires, the potential for engine or electronics contamination due to the use of specific suppression agents is an important factor relative to this study.

Two field surveys were conducted to provide estimates of the magnitude of engine contamination requiring aircraft out of service maintenance and the frequency of incidental or accidental agent discharge. The field surveys were supplemented by telephone inquiries with fire department and aircraft maintenance personnel.

B. AIRCRAFT MAINTENANCE DEPOT SURVEY

Six major Air Force and Navy maintenance centers were contacted to obtain information on decontamination and engine cleanup activities from the use of fire suppression agents. The centers were contacted based on several telephone inquiries regarding flightline damage, local base maintenance procedures, and the role of the maintenance centers. Generally, aircraft engines which are sent to the centers for decontamination and maintenance directly impact aircraft availability and engine inventory pipeline logistics.

A detailed request (Appendix C) was issued to six maintenance facilities in an attempt to collect information on engine decontamination frequency, cost, and logistics impact due to fire incidents and suppression agent contamination. Responses to this request, along with telephone follow-up discussions, revealed that the maintenance centers are unable to provide such information. A consistent response was that field units (i.e., local air bases) do not report the cause of engine contamination or any details regarding incidents associated with the contamination to the maintenance centers. As a result, the frequency or costs associated with fire and suppression agent contamination of aircraft engines cannot be tracked directly from maintenance center records. Several inquiries confirmed that center records could be used to track an individual engine back to the originating base where the cause of contamination may be determined from parallel review of base maintenance and fire department records. However, the resources and time required to implement this approach was beyond the scope of this effort.

C. LOCAL AIR BASE FIRE DEPARTMENT SURVEY

A second survey (Appendix D) was conducted at the base level to determine the magnitude of incidental or accidental suppression agent discharges. Incidental discharges are associated with small fires which do not result in the aircraft being removed from service for extended periods. These cases are routinely not reported to the NSC. Accidental discharges involve non-fire-related incidents on these types of incidents, clean agents, such as Halon 1211 or CO_2 would have little or no impact on aircraft readiness. However, the use of dry chemical or water-based agents would potentially result in the aircraft being removed from service.

1. Base Fire Department Responses

Of the 51 air bases contacted, 25 provided direct responses to the inquiry. Of the 25 responses, 16 base fire departments maintained records of unreported (e.g., not reported to NSC) incidents involving suppression agent discharges. Table 11 provides a summary of inquiries, responses, and number of unreported incidents determined to be relevant to this study. Table 12 provides a breakdown of incidents in terms of incident type. The 357 unreported incidents were evaluated in terms of annualized frequency and amounts and types of agents discharged.

TABLE 11. FIRE DEPARTMENT SURVEYS

Service	Inquiries	Responses	Bases with Unreported Incidents	Number of Unreported Incidents
Air Force	25	11	8	207
Navy	21	11	5	123
Marine Corp	5	3	3	27
Totals	51	25	16	357

TABLE 12. INCIDENT FREQUENCY FOR UNREPORTED FIRES

Incident Type	Number of Incidents	Percent of Total
Engine/Nacelle	82	23
Cold Start	130	36
Electronics/Avionics	45	13
Wheel/Brake Assembly	17	5
Other/Unknown	83	23
Totals	357	100

As illustrated in Table 13, the population of unreported extinguishing agent discharges from the 16 air bases that provided such reports was spread over 8 years, from 1985 through part of 1992. Of the 357 incidents, 225 were associated with actual fires, 120 incidents occurred as a result of "suspected" fires, and 12 incidents were accidental. Assuming that the reported population approximates the general trends for all flightline incidents, accidental discharges appear to occur relatively infrequently. Of the 357 incidents, 345 or 97 percent resulted from observed or suspected fires.

TABLE 13. DISTRIBUTION OF SUPPRESSION AGENT INCIDENTAL DISCHARGES

Year	Agent Discharge Incidents			
	Fire Observed	Fire Suspected	Accidental	Total
1985	4			4
1986	5			5
1987	39	8		47
1988	38	15	1	54
1989	55	26		81
1990	29	32	5	66
1991	39	29	2	70
1992	16	10	4	30
Totals	225	120	12	357
%	63	34	3	

In order to estimate the annualized frequency of such incidents for individual bases, the incidents for 1985, 1986, and 1992 were ignored. The low incident numbers reported for 1985 and 1986 were the result of limitations in records availability. And, the 1992 incidents represent a portion of the year.

If the incidents are evaluated for 1987 through 1991, the frequency of incidental suppression agent discharges is four incidents per year, per individual air base.

Based on survey results, the agent used in nearly all of the cases involving small, unreported incidents was Halon 1211 (Table 14).

While it is difficult to infer the impact on maintenance of changing to a potentially contaminating agent, follow-up inquiries indicated that little or no maintenance is associated with

these types of incidents and the aircraft involved is seldom taken out of service beyond the time required for local inspection and minor repairs. Several fire department personnel indicated the importance of clean agent availability to maintaining continuity in flightline operations. They also indicated that initial fire suppression activities associated with small, incidental fires are routinely performed with gaseous, clean agents to minimize collateral damage.

TABLE 14. FREQUENCY OF SUPPRESSION AGENT USE IN UNREPORTED INCIDENTS

Agent Type	Number of Applications
Halon 1211	350
PKP	1
CO_2	5+
AFFF	3+
Water	1

+In two cases, used in conjunction with Halon 1211.

D. HALON 1211 DISCHARGE AMOUNTS

Table 15 provides a breakdown of Halon 1211 discharge amounts. The total number of cases does not correspond to the 357 incident base because several cases did not include information on the amount of agent discharged.

TABLE 15. HALON 1211 DISCHARGE AMOUNTS (LB)

Service	≤50	51-100	101-150	151-500	>500
Air Force	93	18	19	23	6
Navy	57	39	25	2	1
Marine Corp	4	1	22		
Totals	154	58	66	25	7
Percentage	50	19	21	8	2

The total amount of Halon 1211 discharged between 1987 and 1991 was approximately 25,000 pounds, or on average, 79 pounds per incident. However, as indicated in Table 14, 50 percent of all discharges resulted in 50 pounds or less of Halon 1211 being discharged. And, 90 percent of the discharges resulted in 150 pounds or less.

E. DISCUSSION

Important considerations in estimating the impact of fire suppression agents on flightline operations includes consideration for removal of the aircraft from service. Removal can occur due to many factors including fire damage, contamination of engines and electronics through the use of selected extinguishing agents, or some combination of both.

For fires of significant magnitude, suppression agent contamination is difficult to isolate from fire damage. However, a significant number of agent discharges are associated with small incidental fires or accidents. In these cases, the contamination potential of the extinguishing agent will directly influence the extent of damage and required maintenance and decontamination of the aircraft.

While the information obtained in the surveys and telephone inquiries should be treated as anecdotal, it provides a basis for estimates regarding the potential impact of suppression agent aircraft contamination. Responses to the field surveys indicate that annualized maintenance data that isolate fire and contaminant suppression agent damage are not available. It may be possible to isolate specific cases of interest from the depot records and subsequently trace the maintenance and logistics efforts back to the original base level incident. This approach may represent the only means of determining the effects in sufficient detail to permit assessment of contamination effects of selected suppression agents. However, such an effort would be costly and limited in terms of generalizing the results.

Results from the field surveys also indicate a significant number of small, incidental flightline fires that are readily suppressed. In general, these fires resulted in minimal damage to the aircraft and limited or no removal of the aircraft from service, beyond local maintenance inspection.

Based on the survey results, the majority of such incidents involved the use of Halon 1211. Assuming that the incident reports are representative of typical air base incident frequencies, it is reasonable to estimate that each air base in the Air Force population will experience, on average, four such incidents each year. Currently, these incidents have minimal effect on aircraft maintenance and engine pipeline logistics. However, substitution of an extinguishing agent with contamination potential could increase maintenance demands and decrease aircraft availability significantly.

SECTION VI
AGENT-RELATED DAMAGE POTENTIAL

Concern has been expressed regarding the damage potential associated with selected extinguishing agents under consideration as alternatives to Halon 1211. While the potential for thermal shock is associated with Halon 1211 and CO_2, such effects on aircraft components could not be documented. Neither agent is considered a potential contaminant.

Other agents such as AFFF and PKP are considered potential contaminants, with PKP being the most severe. Navy practice permits water "washdown" of aircraft components exposed to AFFF (Reference 9), but both the Air Force and Navy have extensive repair procedures associated with aircraft exposure to PKP.

The potential impact of substituting a contaminating agent for Halon 1211 for flightline fire fighting may be significant. While the impact of secondary or collateral damage on the aircraft is considered minor for the "large" fire incidents, such incidents are relatively infrequent. However, collateral damage could be quite extensive compared to the actual fire damage for the small or unreported incidents.

Current experience primarily involves the use of Halon 1211 for such incidents. Therefore, collateral damage effects are limited or nonexistent. In order to estimate the potential for such damage, projections were made based on the frequency of small and unreported incidents.

In Sections 4 and 5, estimates of the annual frequency of small and unreported incidents were developed. On average, the Air Force experiences 65 small fire incidents each year, and assuming 150 mission active air bases, 600 unreported incidents also occur each year (4 incidents/year/air base x 150 air bases)[1]. Therefore, an estimated upper bound on the number of flightline incidents where collateral damage due to extinguishing agent contamination could be far more severe than the fire damage is 665 incidents/year.

Since it is unlikely that all small or unreported incidents involve aircraft components that are susceptible to contamination damage from extinguishing agents, an attempt was made to refine the estimate. It would also be appropriate to identify what portion of the incidents result in sufficient damage to initiate major repair procedures, but the maintenance data to identify such cases were not available.

In an effort to estimate the portion of these incidents where the likelihood of collateral damage was reasonably high, the frequency of fire incidents involving damage to critical aircraft components due to agent contamination was estimated. Such fire incidents included engine and nacelle fires, cold start fires, fires exposing electronics and avionics, and wheel/brake assembly

[1]An independent analysis by ARA, Inc. estimates 3-4 incidents/year/air base (Reference 1).

fires. The distribution of these fire incidents are summarized in Table 16 and constitute 53 percent of the reported small fire incident database.

TABLE 16. PORTION OF SMALL FLIGHTLINE FIRE INCIDENTS WHERE COLLATERAL DAMAGE POTENTIAL EXISTS

Fire Scenario	Number of Incidents
Engines/Nacelles	178
Cold Start	92
Electronics/Avionics	75
Wheel/Brake Assemblies	103
Total	448

If one assumes that 53 percent is a reasonable fraction of the annual flightline fire incidents (both reported and unreported) in which collateral damage potential exists, then the Air Force can expect to experience approximately 352 incidents a year where aircraft damage due to a fire may be insignificant, but the potential for collateral damage that could require that the aircraft be removed from service for repairs is quite high.

A. ENGINE FIRES

A subset of this population is engine/nacelle fires, where extensive contamination can occur due to ingestion of contaminant extinguishing agents. Based on the NSC data, the frequency of such incidents (i.e., small engine/nacelle fires) is estimated to be 12 incidents/year. The Navy estimates the cost to clean and repair an engine that ingests dry chemical agent to be approximately one-half the cost of replacement. Based on the NSC data regarding aircraft and engine types, the cost associated with one-half of the engine costs for Navy aircraft ranged from $140,000 to $1,600,000. An estimate provided for Air Force decontamination costs for all aircraft engines was $250,000 (Reference 4).

Based on these cost estimates and 12 incidents/year, an estimate of the cost impact on engine repair and decontamination of using a contaminant extinguishing agent such as PKP can be developed. Table 17 provides a summary of the estimates based on 1992 dollars.

TABLE 17. ANNUAL DECONTAMINATION COST ESTIMATES FOR AIRCRAFT ENGINE COLLATERAL DAMAGE DUE TO CONTAMINANT EXTINGUISHING AGENT

	Repair/ Decontamination Cost/Engine	Estimated Annual Cost "Reported" Fires	Upper Bound Estimated Annual Cost "Reported and Unreported" Fires
Navy (lower bound)	$140,000	$1.7M	$21.0M
Air Force	$250,000	$3.0M	$37.5M
Navy (upper bound)	$1,600,000	$19.2M	$240.0M

The range of these estimates reflects the variation in engine costs for different types of aircraft commonly used by the Air Force and the Navy. The actual costs are dependent on the specific engine type, the extent of contamination, fire damage, and logistical costs such as component parts costs, local and depot maintenance service costs, and shipment. These estimates also do not include aircraft out-of-service and engine pipeline costs. This type of cost information was not available from the maintenance depots.

The estimates in Table 17 do not account for the impact of unreported incidents where engine contamination may occur due to the discharge of an extinguishing agent. The results presented in Section V.C indicate that incidents exposing aircraft engines to extinguishing agent discharges account for approximately one-quarter of the unreported incidents. Therefore, it is reasonable to conclude that one out of every four unreported incidents per year for each air base could potentially result in contamination of an aircraft engine. Assuming 150 mission active air bases, this would result in 150 such incidents per years.

If the estimate of 150 unreported incidents per year involving potential contamination of aircraft engines is included in the cost estimates, the values in Table 17 would increase by more than an order of magnitude. Using the Air Force average estimate of $250,000 to repair/decontaminate an engine, the annual cost for both reported and unreported incidents is on the order of $40.5M. This estimate should be considered an upper bound since it is based on the assumption that all such incidents would require a complete engine overhaul. Available incident data do not provide the necessary detail to refine the estimate in this regard.

SECTION VII
DISCUSSION

A. GENERAL

The scope of this study included review of flightline fire incident experience, the frequency of unreported agent discharges, and information on maintenance associated with secondary damage to aircraft due to extinguishing agent discharge. The field information obtained during this effort, particularly regarding maintenance impact and costs, and agent effectiveness was insufficient to provide a detailed benefit/cost basis for evaluation of fire extinguishing agents on flightline fire fighting effectiveness or mission continuity. Such information may still be retrievable, but will require considerable additional time and resources.

Information was obtained through inquiries to base fire departments and analysis of available Navy Safety Center fire management reports, particularly in terms of fire incident experience, incidental agent discharges, and agent selection and usage.

B. FLIGHTLINE FIRE INCIDENT EXPERIENCE

Analysis of NSC incident data indicates that flightline fire incident experience can be characterized as a bimodal distribution. One group of incidents includes large, potentially catastrophic fires and the other includes relatively small, incidental fires. On an annualized basis, the Air Force experiences 4 to 6 large and 65 small fire incidents each year. Common small-fire scenarios include the following:

- nonaircraft;
- engine/tailpipe/nacelle;
- cold start;
- electronics/avionics;
- wheel/brake assemblies;
- fuel spills/pools;
- fuel leaks/spills; and
- exposure/debris.

Experience indicates that the extinguishment agents of choice for the large fire scenarios include (1) AFFF, (2) water, and (3) PKP dry chemical. This is attributed to the general effectiveness of these agents under large-fire conditions in cooling the fire, shielding exposures from radiation damage, and the availability of large application rates. In discussions with base fire department personnel, it was indicated that secondary damage from agent application is generally not a concern, due to the magnitude of the fire threat itself.

Under the small fire scenario, the primary agent of choice has been Halon 1211 since its replacement of CO_2 on the flightline during the early 1980's. The predominant use of Halon 1211 is attributed to its effectiveness on the primary flightline small fire scenarios and the

negligible potential for secondary or collateral damage to aircraft components due to agent discharge.

Surveys of Air Force, Navy, and Marine Corps air bases indicate that the addition to the NSC reported fires, there are an estimated four incidents/air base/year where extinguishing agents are discharged in close proximity to aircraft but are not reported as fire incidents. Nearly all of these incidents, which result in approximately 600 incidents per year for the Air Force alone, are the result of a small or suspected fire condition which resulted in negligible damages. Only 3 percent of all incidents were attributed to accidental discharges. According to the survey results, Halon 1211 has been the predominant agent discharged (i.e., 98 percent).

Recent studies indicate that the amount of Halon 1211 discharged on the flightline each year is approximately 20,000 pounds for the Air Force. A similar quantity has also been reported for the Navy. These rates would include the discharge of Halon 1211 for small, large, and unreported fire incidents. Results from the surveys of unreported incidents indicate that for 90 percent of the unreported incidents, less than 150 pounds of Halon 1211 were discharged. As expected, this would indicate the predominant use of 150 pound portable Halon 1211 extinguishers on the flightline as the initial agent of choice.

Review of flightline experience and analysis of agent effectiveness and collateral damage potential resulted in development of a rank order for flightline agent preference. Table 18 provides summaries of the rankings for both the large and small flightline fire scenarios.

TABLE 18. PREFERRED RANK OF EXTINGUISHING AGENT EFFECTIVENESS AND SECONDARY DAMAGE POTENTIAL

Large Fires	Small Fires
AFFF	Halon 1211
PKP	CO_2
Water	PKP
Halon 1211	AFFF
CO_2	Water

The rankings reflect the relative importance of agent effectiveness and minimization of secondary damage potential for small fires. They also reflect different objectives and fire fighting strategies for large flightline fires where the need for agent reach, exposure protection, and cooling dominates.

Review of the U.S. Navy Aircraft Firefighting and Rescue Manual (NATOPS) indicates consistency with the preferred ranks developed in this study. Halon 1211 is designated the agent of choice for aircraft fires unless accompanied by large fuel spill fires. NATOPS includes extensive warnings regarding the contamination potential of AFFF and PKP when discharged near an aircraft. And, while CO_2 was the agent of choice before deployment of Halon 1211 on the flightline, the user is cautioned regarding the limited agent discharge distance and the potential for collateral damage due to static charge or thermal shock.

C. HALON 1211 REPLACEMENT OPTIONS

At issue is the replacement of Halon 1211 as a primary extinguishing agent for Air Force flightline fire fighting. Replacement can be achieved by conversion to an existing alternative agent or by development and deployment of a new, substitute for Halon 1211. The primary factors to be considered in this process include the following:

(1) agent fire fighting effectiveness;
(2) potential for collateral damage;
(3) cost of implementation; and
(4) environmental impact.

This study addressed elements of effectiveness and collateral damage potential for several existing agents, including PKP, CO_2, and AFFF, providing a comparison of their expected performance to that of Halon 1211. In summary, none of the existing candidate agents were considered equivalent to Halon 1211.

In focussing on the small and unreported fire incident scenarios, it is expected that only PKP can provide equivalent extinguishment effectiveness under the incident scenarios of interest. However, for the small and unreported fire scenarios, the potential for collateral damage to the aircraft is potentially more significant than the limited fire damage. Of all the flightline agents, PKP has the greatest potential for collateral damage due to aircraft component contamination. Current usage of PKP for such applications is estimated at less than 5 percent of the total small and unreported incidents.

AFFF is less effective on small aircraft fires and can cause collateral damage due to corrosion. While its general effectiveness on fuel spill and exposure fires results in its use extensively for such applications, currently it is used on a limited basis for small fires involving aircraft.

The most attractive existing agent in terms of minimizing the potential for collateral damage is CO_2. Many of the base fire department surveys indicated a lower effectiveness due to agent stream reach and the requirement to maintain high concentrations. And, concerns associated with static discharge and thermal shock were expressed relative to collateral damage and firefighter safety. However, CO_2 is an effective extinguishing agent for many of the small fire scenarios if discharge distances are short and conditions on the flightline permit retention of

the necessary concentrations. In addition, concerns regarding thermal shock potential could not be substantiated from the limited maintenance data. A remaining concern regarding the toxic hazard of CO_2 was considered small since most of the flightline fire incidents did not occur in confined, occupied spaces.

As discussed, none of the existing extinguishing agents evaluated are equivalent to Halon 1211 in terms of both extinguishment effectiveness and collateral damage potential. In the absence of a detailed benefit/cost analysis regarding the ultimate impact on loss potential and mission capability of selecting an alternative agent with lower performance expectations, it appears that development and deployment of a new, replacement agent for Halon 1211 has merit. The relatively large number of small and unreported fires clearly dominate the Air Force flightline fire experience. It appears that prototype replacement agents such as perfluorocarbons and hydrofluorocarbons can provide nearly equivalent performance to Halon 1211. However, there are insufficient test results to assure similar performance on the flightline for the small fire scenarios of interest. Considerable testing would be required to provide this information. Finally, this evaluation does not address environmental issues. Drtailed benefit/cost analyses are required in order to evaluate the many factors associated with these potential strategies.

In support of such an analysis, preliminary estimates of the frequency of incidents where collateral damage could significantly affect losses and mission capabilities were developed. Of the 665 small and unreported incidents that occur each year, 352 of them have a direct likelihood of significant collateral damage from the use of a contaminant extinguishing agent.

A subset of these incidents involved direct aircraft engine fires. At the reported frequency of 12/year, annual costs of repairs were estimated to range from \$1.7 to 19.2M, depending on aircraft type and extent of damage. If the 150 estimated "unreported" engine fires also reported in sufficient agent contamination of the engines to require significant maintenance, the annual cost estimates could range from \$21M to \$240M. For bases involved in mission activities with advanced aircraft, the estimates will approach the higher end of the range, without consideration for mission capability expenses such as additional aircraft and pipeline engine requirements.

D. NONMILITARY POSTURE

A survey was conducted of commercial aircraft and aircraft engine manufacturers, extinguishing agent producers, commercial airport authorities and various government agencies. While concerns were expressed regarding the need for Halon 1211 or an equivalent agent, no significant research had been conducted to develop such an agent. In addition, while the potential for collateral damage of aircraft components due to exposure to contaminant extinguishing agents was well known, no guidance regarding maintenance procedures or damage assessment techniques were available from the agent producers or the aircraft engine manufacturers.

E. STUDY LIMITATIONS

The absence of data on the frequency and extent of collateral damage to aircraft required that the potential impact be estimated from fire incident data. In addition, the NSC fire management reporting system does not include information on collateral damage or whether or not an aircraft was removed from service. These limitations in available information prohibited development of a detailed assessment of collateral damage effects.

Discussions with base and depot maintenance personnel indicated that it would be difficult to differentiate between repairs due to fire exposure and those due to agent discharge contamination. Rather than attempt to develop a statistical basis, a more promising approach could be to isolate major depot engine repairs and track the engines back through the system to the originating air base. In this way, depot and base level records could be matched and several case histories could be developed for comparison.

There was a dearth of information in the literature on agent effectiveness and damage potential for both existing and developmental agents. This was particularly true for the range of flightline small fire scenarios. Extensive performance testing of proposed Halon 1211 replacement agents is necessary in order to project the flightline impact of these agents.

SECTION VIII
SUMMARY AND CONCLUSIONS

The phase-out and replacement of Halon 1211 as a primary flightline fire extinguishing agent is under consideration by the Air Force due to its potential adverse impact on the environment. Candidate solutions include development of a replacement agent having similar fire fighting characteristics or conversion to an existing agent such as dry chemical (PKP).

This study included investigation of reported flightline fire incidents, unreported incidents involving agent discharge, inquires to the primary maintenance depots regarding frequency and cost of aircraft repairs due to fire damage and agent contamination, and inquiries to air base fire departments regarding the frequency of unreported agent discharges. It also included inquires to the commercial airport authorities, aircraft and engine manufacturers, and extinguishing agent manufacturers to obtain information on agent selection, contamination potential, recommended maintenance and repairs, and associated costs.

Inquiries to the depots revealed limited useful information. Statistical information regarding aircraft contamination and maintenance frequency or costs are not maintained by the depots in a manner that would permit direct determination of the impact of a fire extinguishing agent. In addition, the aircraft and engine manufacturers expressed concerns regarding the use of potentially contaminating fire extinguishing agents, but had no standard protocol or maintenance guidelines related to such incidents.

Analysis of flightline fire incident data revealed a bimodal distribution, one group involving large, catastrophic fires and the other involving small, incidental fires. The latter group comprised 95 percent of the annual incidents (i.e., 65 incidents/year). This is significant in that these small fires typically did not result in extensive damage (i.e., $12K/incident), but are highly susceptible to collateral damage from a contaminating extinguishing agent. In addition, it was estimated that the Air Force encounters 352 "unreported" agent discharges on the flightline annually that also have a high potential for collateral damage. Currently, most (95 percent) of these reported and unreported incidents involve the discharge of Halon 1211, a noncontaminating agent.

While a detailed cost/benefit analysis was outside the scope of this study, upper bound estimates were developed for the potential repair and maintenance costs associated with the use of a contaminating agent for the fires where it was determined that engine contamination was highly likely. This subset of the incidents included 12 engine fire incidents and 150 unreported agent discharge incidents annually. Based on the average repair cost for contaminated aircraft engines by the Air Force ($250,000), it was estimated that annual repair/maintenance costs of up to $40.5M could be incurred due to the use of a contaminant fire extinguishing agent on the flightline.

General conclusions, based on the results of this study, are the following:

(1) For both the Air Force and the Navy, the agent used most frequently for small and unreported incidents is Halon 1211. Small fire incidents represent 95 percent of flightline fires. The relatively low per incident loss estimates (i.e., $12.2K per incident) are partly attributable to minimal collateral damage associated with the use of Halon 1211. The amount of Halon 1211 discharged per incident was 150 pounds or less for 90 percent of the unreported incidents, indicating the use of one 150 pound flightline extinguisher.

(2) The frequency of "reported" and "unreported" Air Force flightline aircraft fires involving the discharge of extinguishing agents indicates that conversion from Halon 1211 to a potentially contaminating agent such as dry chemical will have a significant adverse impact on aircraft "out of service" and repair costs. An upper-bound estimate of annual Air Force repair costs due to reported and unreported agent discharges which expose aircraft engines is $40.5M. This assumes that in all cases, the agent is a contaminant and is discharged into the engine, resulting in out of service maintenance/repairs.

The following detailed conclusions summarize additional results from this study.

(1) For the Air Force, the frequency of "reported" small engine fires where potential extinguishing agent contamination could necessitate removal of the engine for major repairs was estimated at 12 incidents/year, based on the NSC incident data. Annual total repair costs associated with these incidents ranged from $1.7 to 19.2M, depending on the aircraft type. This range does not include consideration for replacement aircraft or pipeline engine inventory requirements.

(2) An assessment of agent extinguishment effectiveness and collateral damage potential resulted in Halon 1211 being ranked as the most effective agent for use on small aircraft fire incidents. Small fire incidents represent 95 percent of flightline fires.

(3) The Navy NATOPS agent of choice for small flightline fire fighting is Halon 1211, which replaced CO_2 in the early 1980's. Warnings are provided in NATOPS regarding collateral damage potential with CO_2, PKP, and AFFF.

(4) None of the existing agents evaluated (AFFF, PKP, CO_2) were determined to be equivalent to Halon 1211 in terms of both effectiveness and collateral damage potential. However, insufficient information was

available to quantify these differences, which may be relatively small in some cases.

(5) Air Force and Navy flightline fire incident experience is characterized by a simple bimodal distribution. One group of fires are small, incidental fires that generally are extinguished with minor damage (i.e., $12.2K/incident). This group constitutes 95 percent of the incidents. The other group consists of large fires which are infrequent but result in substantial losses, on the order of $1.9M per incident.

(6) The frequency of small incidental fires is estimated at 65 incidents/year for the Air Force.

(7) The frequency of small "unreported" incidents involving extinguishing agent discharge is estimated at four incidents/air base/year. Incidents involving aircraft engines account for 25 percent or 150 such incidents per year. Using the internal Air Force provided estimate for engine repair costs ($250,000), the potential impact of conversion to a contaminant agent could be as high as $37.5M each year (upper bound estimate) for those incidents involving exposure of aircraft engines.

(8) The upper bound estimate of the number of small or unreported incidents where collateral damage due to contamination by an extinguishing agent was determined to be 665 incidents/year. Assuming only selected small scenarios are actually applicable, the number of incidents was conservatively refined to a frequency of 352 incidents/year.

(9) Limited information was available from engine and aircraft manufacturers and extinguishing agent producers regarding collateral damage potential and required or recommended repair/maintenance procedures

(10) The annual amount of Halon 1211 discharged in flightline incidents is estimated at approximately 20,000 pounds for the Air Force. A similar amount was reported by the Navy.

(11) An assessment of available extinguishing agents in terms of effectiveness and damage potential resulted in AFFF being ranked as the most appropriate agent for "large" fire scenarios and Halon 1211 for "small" fire scenarios for flightline fire fighting.

(12) Adoption of CO_2 as the primary flightline agent could result in an increase in the number of "large" fires due to the lower effectiveness. Limitations on effectiveness of CO_2 for flightline fire scenarios should be examined if such a strategy is contemplated.

(13) Several candidate replacement agents are under development, including perfluorocarbons and hydrofluorocarbons. Considerable work remains to evaluate their environmental impact and their effectiveness on flightline fire incidents.

(14) Air Force maintenance records do not distinguish between fire and contamination caused damage to aircraft components.

(15) Based on analysis of flightline fire incidents, it appears that selection of a replacement for Halon 1211 on the flightline should be based on evaluation of the agents' effectiveness and collateral damage potential under the frequent "small" fire scenarios identified in the incident records, and the cost of deployment.

SECTION IX
RECOMMENDATIONS

(1) Replacement strategies for Halon 1211 for flightline fire fighting should be developed based on extinguishment effectiveness and collateral damage potential associated with the predominant "small" fire scenarios. This would dictate the need for a non-contaminating agent of similar fire fighting effectiveness to Halon 1211.

(2) Continue development efforts for a Halon 1211 replacement that will preserve extinguishment effectiveness and negligible collateral damage potential for flightline fire fighting.

(3) Utilize a broad based benefit/cost analysis methodology (e.g., Decision Analysis) to evaluate alternative strategies for Halon 1211 replacement.

(4) Modify the Air Force incident and maintenance reporting system to permit tracking of such cases through the system on a routine basis.

(5) Develop a series of case studies that track damage and maintenance/repair costs from the maintenance depots back to the originating air bases in order to separate the costs associated with fire damage from damage due to agent discharge. If possible, several of the cases should be selected to represent collateral damage only (i.e., unreported incidental agent discharge).

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APPENDIX A
SAMPLE NAVY SAFETY CENTER FIRE MANAGEMENT REPORT

JOB NUMBER: R0511EA
JOB TITLE: NAVY FLIGHTLINE FIRE TYPE INCIDENTS   10 DEC 91
TIME FRAME: JAN 75 THRU DEC 80
PREPARED BY: AVIATION/SHORE BRANCH, NAVSAFECEN

RECORD ID: 78011090800   DATE OF FIRE: 10 JAN 78   REPORTING FIRE DEPT: NAVAL BASE NORFOLK VA 23511
REPORTING FD SVC AFFIL: NAVY

REPORT STATUS: FINAL   OFF-STA/MUTUAL AID RESP: NO
FIRE LOCATION: NAVAL AIR REWORK FACILITY NAS NORFOLK VA
INCIDENT NO.:   DAY OF WEEK: TUE
FIXED PROPERTY: MAINTENANCE/INSPECTION
ALARM METHOD: TELEPHONE TIE-LINE TO FIRE DEPARTMENT
AREA OF ORIGIN: SERVICE, EQUIPMENT AREA NOT CLASSIFIED
TERM STAGE: FIRE TERMINATED IN OR AFTER FLAME STAGE
TYPE MATL IGNITED: CLASS II COMBUSTIBLE LIQUID
HEAT OF IGNITION: HEAT, SPARK FROM FRICTION
STRUCTURE TYPE: NOT A STRUCTURE
DETECTION METHOD: OCCUPANTS

MUTUAL AID RECEIVED: NO
SERVICE AFFILIATION: NAVY
TIMES: FIRE STARTED: DETECTED: ALARM RECVD: 1333
FD ARRIVED: FIRE EXTINGUISHED:
SITUATION FOUND: OUTSIDE SPILL, LEAK WITH ENSUING FIRE
LEVEL OF ORIGIN: GRADE LEVEL TO 9 FEET ABOVE GRADE
NUMBER PEOPLE RESCUED: 0
FORM MATL IGNITED: FUEL
IGNITION FACTOR: MECHANICAL FAILURE, MALF NOT CLASSIFIED
EXTING METHOD: EXTINGUISHED BY FIRE DEPARTMENT
HAND OR PORTABLE FIRE EQUIPMENT

MOST EFF EXTING AGENT: OTHER FOAMS - PROTEIN, HIGH EXPANSION AGENTS   PROBLEM AREAS: NONE REPORTED

AGENT(S) USED: NONE/NOT REPORTED

MOBILE PROPERTY TYPE: FIGHTER OR ATTACK
YEAR: MAKE: MODEL: F-14   SERIAL NO: 158634   LICENSE NO:

EQUIPMENT INVOLVED TYPE: NO EQUIPMENT INVOLVED

AUTOMATIC SPRINKLERS -- PROVIDED: NO

AUTOMATIC FIRE ALARM -- PROVIDED: NO

MANUAL FIRE ALARM -- PROVIDED: NO

PORTABLE EXTINGUISHERS: N/A

SPECIAL EXTING SYSTEMS IN FIRE AREA: NONE

	GOVERNMENT PROPERTY DAMAGE LOSSES			NON GOVERNMENT PROPERTY DAMAGE LOSSES		NUMBER OF	
	STRUCTURE/MOBILE	CONTENTS	TOTAL	TOTAL	TYPE PROPERTY	INJ	DEATHS
VALUE:	$0	$0	$0	$0			
LOSS:	$0	$0	$0	$0		0	0

AT 1333 UPON RECEIPT OF CALL FM NAS CRASH REPORTING HANGAR DOOR FALLING ON PLANE IN LP167. ON ARRIVAL FOUND AN F-14 HAD BROKEN AWAY DURING ENGINE TURN UP STRIKING CARRY-ALL USN#14-21027 AND A NC-5B STARTING UNIT 604656. PLANE THEN HIT CENTER EAST BAY HANGAR DOORS BEFORE STOPPING INSIDE HANGAR. CRASH TRUCK ON HOT SPOT SEEING SMOKE RESPONDED TO AND EXTINGUISHED FIRE THAT HAD STARTED BENEATH AIRCRAFT. REPORTED 2 MEN TRAPPED AND REQUESTED AMBULANCES. CRASH CREW EFFECTED RESCUE OF MECHANIC TRAPPED IN PLANE. FD DISSIPATED GAS FM HANGAR DECK. INJURED PERSONNEL TRANSPORTED TO DISPENSARY, TREATED AND RELEASED FOR DUTY. DAMAGE REPORTED VIA AIRCRAFT REPORTING INST. NON-BURN INJURIES.

Incident Data Entry Form

Incident No. - ______________
Year - ______________
Service - ______________ (1) USAF (2) US Navy

Property Type ______________

(1) Aircraft
(2) Equipment
(3) Structures
(4) Vehicle
(5) Other

Fire Incident Type (Aircraft Only) ____________

(1) Engine
(2) Cold Start
(3) Electrical/Electronics
(4) Wheel/Brake Assembly
(5) Fuel Spill
(6) Fuel Leak
(7) Exposure
(8) Other

Fire Incident Type (Non-Aircraft) ____________

(1) Class A Combustibles
(2) Class B Liquid Fuel
(3) Class C Electrical
(4) Other

Explosion Involved (Y/N) ___________

Fire Involvement ___________

(1) No Fire
(2) Smoldering
(3) Small Flaming
(4) Large Flaming

Extinguishing Agent Used - Primary _____ Secondary ______ Additional _____

(1) 1211
(2) CO_2
(3) Dry Chemical
(4) AFFF
(5) Other

Application Method - Primary ______ Secondary ______ Additional ______

(1) Hand-held portable
(2) Wheeled Unit
(3) CFR Turret

Agent Quantity - Primary ______ Secondary ______ Additional ______

Total Property Value $__________

Total Damage/Loss $__________

Injuries __________

Deaths __________

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APPENDIX B
SUMMARIZED NSC REPORTED FLIGHTLINE FIRE INCIDENTS

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U.S. Air Force Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1981-91)
All Incident Types

Year	No. of Incidents	Dollar Loss	Avg. Loss /Incident	No. of Injuries	No. of Deaths
1981	1	69	69	0	0
1984	54	872,424	16,156	22	0
1985	96	5,125,416	53,390	17	0
1986	87	3,329,205	38,267	9	3
1987	81	27,642,325	341,263	34	1
1988	62	25,084,618	404,591	21	0
1989	52	4,113,481	79,105	15	2
1990	56	1,490,127	26,609	13	0
1991	26	776,364	29,860	13	0
Totals	515	68,434,029	132,882	144	6

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U.S. Air Force Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1981-91)
Incident Types
Small, Smoldering, No Fire

Year	No. of Incidents	Dollar Loss	Avg. Loss /Incident	Injuries	Deaths
1981	1	69	69	0	0
1984	54	872,424	16,156	22	0
1985	88	1,016,354	11,549	15	0
1986	83	932,634	11,237	8	3
1987	73	320,421	4,389	6	0
1988	55	535,774	9,741	4	0
1989	50	475,481	9,510	4	0
1990	53	1,424,006	26,868	8	0
1991	23	436,364	18,972	13	0
Totals	480	6,013,527	12,528	80	3

U.S. Air Force Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1981-91)
Incident Types
Large Fires

Year	No. of Incidents	Dollar Loss	Avg. Loss /Incident	Injuries	Deaths
1985	8	4,109,062	513,633	2	0
1986	4	2,396,571	599,143	1	0
1987	8	27,321,904	3,415,238	28	1
1988	7	24,548,844	3,506,978	17	0
1989	2	3,638,000	1,819,000	11	2
1990	3	66,121	22,040	5	0
1991	3	340,000	113,333	0	0
Totals	35	62,420,502	1,783,443	64	3

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U.S. Air Force Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1981-91)
Small, Smoldering, No Fire Incident Types
No. Of Incidents By Primary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1981	1	0	0	0	0
1984	26	3	2	18	3
1985	43	3	3	29	7
1986	46	2	4	22	5
1987	42	4	4	15	2
1988	35	1	2	12	1
1989	47	0	1	2	0
1990	45	0	0	6	2
1991	23	0	0	0	0
Totals	308	13	16	104	20

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U.S. Air Force Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1981-91)
Small, Smoldering, No Fire Incident Types
Total Dollar Loss By Primary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1981	69	0	0	0	0
1984	810,292	670	9,276	47,770	162
1985	389,172	145	6,025	615,999	307
1986	296,919	500	975	603,945	20
1987	152,764	9,748	34,946	92,948	3,297
1988	449,126	50	1,961	83,049	0
1989	365,481	0	0	110,000	0
1990	462,432	0	0	736,574	225,000
1991	436,364	0	0	0	0
Totals	3,362,619	11,113	53,183	2,290,285	228,786

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U.S. Air Force Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1981-91)
Small, Smoldering, No Fire Incident Types
Average Dollar Loss per Incident By Primary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1981	69	0	0	0	0
1984	31,165	223	4,638	2,654	54
1985	9,051	48	2,008	21,241	44
1986	6,455	250	244	27,452	4
1987	3,637	2,437	8,737	6,197	1,649
1988	12,832	50	981	6,921	0
1989	7,776	0	0	55,000	0
1990	10,276	0	0	122,762	112,500
1991	18,972	0	0	0	0
Totals	10,918	855	3,324	22,022	11,439

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U.S. Air Force Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1981-91)
Small, Smoldering, No Fire Incident Types
No. Of Incidents By Secondary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1984	7	1	0	2	0
1985	3	1	2	1	0
1986	5	0	1	3	1
1987	7	1	1	0	0
1988	7	1	0	2	0
1989	7	0	3	2	3
1990	13	0	0	1	1
1991	1	0	0	0	1
Totals	50	4	7	11	6

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U.S. Air Force Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1981-91)
Small, Smoldering, No Fire Incident Types
Total Dollar Loss By Secondary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1984	747,324	8,555	0	2,600	0
1985	560	55	5,300	250	0
1986	4,257	0	7,000	0	2,933
1987	102,384	860	8,000	0	0
1988	81,148	1,573	0	11,372	0
1989	35,666	0	90,000	2,000	61,977
1990	998,328	0	0	0	0
1991	9,750	0	0	0	23,719
Totals	1,979,417	11,043	110,300	16,222	88,629

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U.S. Air Force Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1981-91)
Small, Smoldering, No Fire Incident Types
Average Dollar Loss per Incident By Secondary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1984	106,761	8,555	0	1,300	0
1985	187	55	2,650	250	0
1986	851	0	7,000	0	2,933
1987	14,626	860	8,000	0	0
1988	11,593	1,573	0	5,686	0
1989	5,095	0	30,000	1,000	20,659
1990	76,794	0	0	0	0
1991	9,750	0	0	0	23,719
Totals	39,588	2,761	15,757	1,475	14,772

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U.S. Navy Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1977-91)
All Incident Types

Year	No. of Incidents	Dollar Loss	Avg. Loss /Incident	No. of Injuries	No. of Deaths
1977	1	2,627,600	2,627,600	6	0
1978	18	52,607	2,923	2	0
1979	15	23,314	1,554	1	0
1980	14	2,835,244	202,517	3	0
1981	12	19,445	1,620	1	0
1982	22	94,457	4,294	1	0
1983	13	109,794	8,446	0	0
1984	28	372,145	13,291	4	0
1985	62	1,361,823	21,965	0	0
1986	49	1,379,023	28,143	2	0
1987	54	273,394	5,063	3	0
1988	46	1,037,730	22,559	3	0
1989	19	293,413	15,443	2	1
1990	12	700	58	0	0
1991	15	149,780	9,985	3	0
Totals	380	10,630,469	27,975	31	1

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U.S. Navy Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1977-91)
Incident Types
Small, Smoldering, No Fire

Year	No. of Incidents	Dollar Loss	Avg. Loss /Incident	Injuries	Deaths
1978	18	52,607	2,923	2	0
1979	14	7,993	571	0	0
1980	10	7,284	728	1	0
1981	12	19,445	1,620	1	0
1982	19	22,283	1,173	0	0
1983	13	109,794	8,446	0	0
1984	28	372,145	13,291	4	0
1985	61	961,823	15,768	0	0
1986	48	1,279,023	26,646	2	0
1987	53	238,394	4,498	3	0
1988	45	937,730	20,838	3	0
1989	18	30,470	1,693	0	0
1990	12	700	58	0	0
1991	15	149,780	9,985	3	0
Totals	366	4,189,471	11,447	19	0

U.S. Navy Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1977-91)
Incident Types
Large Fires

Year	No. of Incidents	Dollar Loss	Avg Loss /Incident	Injuries	Deaths
1977	1	2,627,600	2,627,600	6	0
1979	1	15,321	15,321	1	0
1980	4	2,827,960	706,990	2	0
1982	3	72,174	24,058	1	0
1985	1	400,000	400,000	0	0
1986	1	100,000	100,000	0	0
1987	1	35,000	35,000	0	0
1988	1	100,000	100,000	0	0
1989	1	262,943	262,943	2	1
Totals	14	6,440,998	460,071	12	1

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U.S. Navy Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1977-91)
Small, Smoldering, No Fire Incident Types
No. Of Incidents By Primary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1978	0	12	2	3	1
1979	0	6	2	2	2
1980	0	9	1	0	0
1981	1	4	3	1	2
1982	0	11	2	0	4
1983	4	4	4	0	0
1984	8	8	3	1	5
1985	26	6	5	7	7
1986	22	7	2	9	4
1987	29	8	2	6	2
1988	26	5	2	2	4
1989	18	0	0	0	0
1990	12	0	0	0	0
1991	15	0	0	0	0
Totals	161	80	28	31	31

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U.S. Navy Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1977-91)
Small, Smoldering, No Fire Incident Types
Total Dolla Loss By Primary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1978	0	4,465	43,600	4,542	0
1979	0	4,124	1,950	1,000	369
1980	0	7,134	150	0	0
1981	2,701	402	15,317	300	725
1982	0	5,089	1,543	0	451
1983	5,495	575	103,724	0	0
1984	12,150	118,742	173,500	400	2,403
1985	194,964	109,500	34,795	214,921	354,271
1986	50,220	178,017	2,100	1,005,810	16,115
1987	105,875	9,023	1,183	114,420	4,200
1988	733,099	78,100	0	18,120	2,894
1989	30,470	0	0	0	0
1990	700	0	0	0	0
1991	149,780	0	0	0	0
Totals	1,285,454	515,171	377,862	1,359,513	381,428

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U.S. Navy Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1977--91)
Small, Smoldering, No Fire Incident Types
Average Dollar Loss per Incident By Primary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1978	0	372	21,800	1,514	0
1979	0	687	975	500	185
1980	0	793	150	0	0
1981	2,701	101	5,106	300	363
1982	0	463	772	0	113
1983	1,374	144	25,931	0	0
1984	1,519	14,843	57,833	400	481
1985	7,499	18,250	6,959	30,703	50,610
1986	2,283	25,431	1,050	111,757	4,029
1987	3,651	1,128	592	19,070	2,100
1988	28,196	15,620	0	9,060	724
1989	1,693	0	0	0	0
1990	58	0	0	0	0
1991	9,985	0	0	0	0
Totals	7,984	6,440	13,495	43,855	12,304

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U.S. Navy Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1977-91)
Small, Smoldering, No Fire Incident Types
No. Of Incidents By Secondary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1978	0	1	4	0	2
1979	0	0	1	1	0
1980	0	0	1	1	0
1981	0	0	0	0	1
1982	0	0	3	0	0
1983	0	0	0	0	1
1984	2	0	0	0	1
1985	2	0	2	5	2
1986	3	0	0	2	2
1987	2	1	1	1	3
1988	0	2	1	0	0
1989	1	2	1	1	0
1991	0	0	0	1	0
Totals	10	6	14	12	12

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U.S. Navy Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1977-91)
Small, Smoldering, No Fire Incident Types
Total Dollar Loss By Secondary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1978	0	200	48,292	0	300
1979	0	0	1,000	0	0
1980	0	0	80	2,000	0
1981	0	0	0	0	0
1982	0	0	1,800	0	0
1983	0	0	0	0	24
1984	3,000	0	0	0	172,000
1985	0	0	7,000	188,614	17,830
1986	34,000	0	0	12,150	987,300
1987	1,183	450	0	5,400	5,785
1988	0	48,771	149,995	0	0
1989	7,406	0	300	16,100	0
1991	0	0	0	50,000	0
Totals	45,589	49,421	208,467	274,264	1,183,239

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U.S. Navy Flightline Fire Incident Data
Summary Statistics

Yearly Totals (1977-91)
Small, Smoldering, No Fire Incident Types
Average Dollar Loss per Incident By Secondary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1978	0	200	12,073	0	150
1979	0	0	1,000	0	0
1980	0	0	80	2,000	0
1981	0	0	0	0	0
1982	0	0	600	0	0
1983	0	0	0	0	24
1984	1,500	0	0	0	172,000
1985	0	0	3,500	37,723	8,915
1986	11,333	0	0	6,075	493,650
1987	592	450	0	5,400	1,928
1988	0	24,386	149,995	0	0
1989	7,406	0	300	16,100	0
1991	0	0	0	50,000	0
Totals	4,559	8,237	14,891	22,855	98,603

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Flightline Fire Incident Data - Combined Forces
Summary Statistics

Yearly Totals (1977-91)
All Incident Types

Year	No. of Incidents	Dollar Loss	Avg. Loss /Incident	No. of Injuries	No. of Deaths
1977	1	2,627,600	2,627,600	6	0
1978	18	52,607	2,923	2	0
1979	15	23,314	1,554	1	0
1980	14	2,835,244	202,517	3	0
1981	13	19,514	1,501	1	0
1982	22	94,457	4,294	1	0
1983	13	109,794	8,446	0	0
1984	82	1,244,569	15,178	26	0
1985	158	6,487,239	41,058	17	0
1986	136	4,708,228	34,619	11	3
1987	135	27,915,719	206,783	37	1
1988	108	26,122,348	241,874	24	0
1989	71	4,406,894	62,069	17	3
1990	68	1,490,827	21,924	13	0
1991	41	926,144	22,589	16	0
Totals	895	79,064,498	88,340	175	7

3/20/92

Flightline Fire Incident Data - Combined Forces
Summary Statistics

Yearly Totals (1977-91)
Incident Types
Small, Smoldering, No Fire

Year	No. of Incidents	Dollar Loss	Avg. Loss /Incident	Injuries	Deaths
1978	18	52,607	2,923	2	0
1979	14	7,993	571	0	0
1980	10	7,284	728	1	0
1981	13	19,514	1,501	1	0
1982	19	22,283	1,173	0	0
1983	13	109,794	8,446	0	0
1984	82	1,244,569	15,178	26	0
1985	149	1,978,177	13,276	15	0
1986	131	2,211,657	16,883	10	3
1987	126	558,815	4,435	9	0
1988	100	1,473,504	14,735	7	0
1989	68	505,951	7,440	4	0
1990	65	1,424,706	21,919	8	0
1991	38	586,144	15,425	16	0
Totals	846	10,202,998	12,060	99	3

Flightline Fire Incident Data - Combined Forces
Summary Statistics

Yearly Totals (1977-91)
Incident Types
Large Fires

Year	No. of Incidents	Dollar Loss	Avg. Loss /Incident	Injuries	Deaths
1977	1	2,627,600	2,627,600	6	0
1979	1	15,321	15,321	1	0
1980	4	2,827,960	706,990	2	0
1982	3	72,174	24,058	1	0
1985	9	4,509,062	501,007	2	0
1986	5	2,496,571	499,314	1	0
1987	9	27,356,904	3,039,656	28	1
1988	8	24,648,844	3,081,106	17	0
1989	3	3,900,943	1,300,314	13	3
1990	3	66,121	22,040	5	0
1991	3	340,000	113,333	0	0
Totals	49	68,861,500	1,405,337	76	4

3/20/92

Flightline Fire Incident Data -Combined Forces
Summary Statistics

Yearly Totals (1977-91)
Small, Smoldering, No Fire Incident Types
No. Of Incidents By Primary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1978	0	12	2	3	1
1979	0	6	2	2	2
1980	0	9	1	0	0
1981	2	4	3	1	2
1982	0	11	2	0	4
1983	4	4	4	0	0
1984	34	11	5	19	8
1985	69	9	8	36	14
1986	68	9	6	31	9
1987	71	12	6	21	4
1988	61	6	4	14	5
1989	65	0	1	2	0
1990	57	0	0	6	2
1991	38	0	0	0	0
Totals	469	93	44	135	51

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Flightline Fire Incident Data - Combined Forces
Summary Statistics

Yearly Totals (1977-91)
Small, Smoldering, No Fire Incident Types
Total Dollar Loss By Primary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1978	0	4,465	43,600	4,542	0
1979	0	4,124	1,950	1,000	369
1980	0	7,134	150	0	0
1981	2,770	402	15,317	300	725
1982	0	5,089	1,543	0	451
1983	5,495	575	103,724	0	0
1984	822,442	119,412	182,776	48,170	2,565
1985	584,136	109,645	40,820	830,920	354,578
1986	347,139	178,517	3,075	1,609,755	16,135
1987	258,639	18,771	36,129	207,368	7,497
1988	1,182,225	78,150	1,961	101,169	2,894
1989	395,951	0	0	110,000	0
1990	463,132	0	0	736,574	225,000
1991	586,144	0	0	0	0
Totals	4,648,073	526,284	431,045	3,649,798	610,214

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Flightline Fire Incident Data - Combined Forces
Summary Statistics

Yearly Totals (1977-91)
Small, Smoldering, No Fire Incident Types
Average Dollar Loss per Incident By Primary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1978	0	372	21,800	1,514	0
1979	0	687	975	500	185
1980	0	793	150	0	0
1981	1,385	101	5,106	300	363
1982	0	463	772	0	113
1983	1,374	144	25,931	0	0
1984	24,189	10,856	36,555	2,535	321
1985	8,466	12,183	5,103	23,081	25,327
1986	5,105	19,835	513	51,928	1,793
1987	3,643	1,564	6,022	9,875	1,874
1988	19,381	13,025	490	7,226	579
1989	6,092	0	0	55,000	0
1990	8,125	0	0	122,762	112,500
1991	15,425	0	0	0	0
Totals	9,911	5,659	9,796	27,036	11,965

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Flightline Fire Incident Data -Combined Forces
Summary Statistics

Yearly Totals (1977-91)
Small, Smoldering, No Fire Incident Types
No. Of Incidents By Secondary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1978	0	1	4	0	2
1979	0	0	1	1	0
1980	0	0	1	1	0
1981	0	0	0	0	1
1982	0	0	3	0	0
1983	0	0	0	0	1
1984	9	1	0	2	1
1985	5	1	4	6	2
1986	8	0	1	5	3
1987	9	2	2	1	3
1988	7	3	1	2	0
1989	8	2	4	3	3
1990	13	0	0	1	1
1991	1	0	0	1	1
Totals	60	10	21	23	18

3/20/92

Flightline Fire Incident Data - Combined Forces
Summary Statistics

Yearly Totals (1977-91)
Small, Smoldering, No Fire Incident Types
Total Dollar Loss By Secondary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1978	0	200	48,292	0	300
1979	0	0	1,000	0	0
1980	0	0	80	2,000	0
1981	0	0	0	0	0
1982	0	0	1;800	0	0
1983	0	0	0	0	24
1984	750,324	8,555	0	2,600	172,000
1985	560	55	12,300	188,864	17,830
1986	38,257	0	7,000	12,150	990,233
1987	103,567	1,310	8,000	5,400	5,785
1988	81,148	50,344	149,995	11,372	0
1989	43,072	0	90,300	18,100	61,977
1990	998,328	0	0	0	0
1991	9,750	0	0	50,000	23,719
Totals	2,025,006	60,464	318,767	290,486	1,271,868

3/20/92

Flightline Fire Incident Data - Combined Forces
Summary Statistics

Yearly Totals (1977-91)
Small, Smoldering, No Fire Incident Types
Average Dollar Loss per Incident By Secondary Agent Type

Year	Halon	CO2	PKP	AFFF	Water
1978	0	200	12,073	0	150
1979	0	0	1,000	0	0
1980	0	0	80	2,000	0
1981	0	0	0	0	0
1982	0	0	600	0	0
1983	0	0	0	0	24
1984	83,369	8,555	0	1,300	172,000
1985	112	55	3,075	31,477	8,915
1986	4,782	0	7,000	2,430	330,078
1987	11,507	655	4,000	5,400	1,928
1988	11,593	16,781	149,995	5,686	0
1989	5,384	0	22,575	6,033	20,659
1990	76,794	0	0	0	0
1991	9,750	0	0	50,000	23,719
Totals	33,750	6,046	15,179	12,630	70,659

3/23/92

Flightline Fire Incident Data - Combined Forces
Summary Statistics

Yearly Totals (1977-91)
All Fire Incident Sizes
No. of Incidents By Primary Property And Fire Type

Year	Non A/C All Fires	Aircraft Engine Fire	Cold Start	Elect. Avion.	Wheel Brake	Fuel Spill	Fuel Leak	Expos.	Other
1977	1	0	0	0	0	0	0	0	0
1978	17	0	0	0	0	1	0	0	0
1979	13	2	0	0	0	0	0	0	0
1980	12	0	0	0	0	0	0	0	2
1981	10	0	0	0	1	0	0	0	2
1982	20	1	0	1	0	0	0	0	0
1983	11	1	0	0	1	0	0	0	0
1984	10	21	9	10	6	17	4	0	5
1985	22	31	19	14	22	34	7	0	9
1986	28	28	16	13	10	29	1	0	11
1987	28	21	22	12	19	15	4	0	14
1988	25	30	4	10	12	11	8	2	6
1989	13	19	8	7	15	2	2	0	5
1990	7	17	9	7	14	0	5	0	9
1991	6	16	7	3	4	0	0	1	4
Totals	223	187	94	77	104	109	31	3	67

3/23/92

Flightline Fire Incident Data - Combined Forces
Summary Statistics

Yearly Totals (1977-91)
Fire Incident Sizes
Small, Smoldering, No Fire
No. of Incidents By Primary Property and Fire Type

	Non A/C				Aircraft				
Year	All Fires	Engine Fire	Cold Start	Elect. Avion.	Wheel Brake	Fuel Spill	Fuel Leak	Expos.	Other
1978	17	0	0	0	0	1	0	0	0
1979	12	2	0	0	0	0	0	0	0
1980	10	0	0	0	0	0	0	0	0
1981	10	0	0	0	1	0	0	0	2
1982	18	0	0	1	0	0	0	0	0
1983	11	1	0	0	1	0	0	0	0
1984	10	21	9	10	6	17	4	0	5
1985	20	30	19	13	22	34	2	0	9
1986	28	27	16	12	9	29	1	0	9
1987	26	18	20	12	19	15	4	0	12
1988	22	28	4	10	12	10	8	2	4
1989	13	19	8	7	15	1	2	0	3
1990	7	17	9	7	14	0	3	0	8
1991	5	15	7	3	4	0	0	0	4
Totals	209	178	92	75	103	107	24	2	56

Flightline Fire Incident Data - Combined Forces
Summary Statistics

Yearly Totals (1977-91)
Fire Incident Sizes
Large Fires
No. of Incidents By Primary Property and Fire Type

Year	Non A/C All Fires	Aircraft Engine Fire	Cold Start	Elect. Avion.	Wheel Brake	Fuel Spill	Fuel Leak	Expos.	Other
1977	1	0	0	0	0	0	0	0	0
1979	1	0	0	0	0	0	0	0	0
1980	2	0	0	0	0	0	0	0	2
1982	2	1	0	0	0	0	0	0	0
1985	2	1	0	1	0	0	5	0	0
1986	0	1	0	1	1	0	0	0	2
1987	2	3	2	0	0	0	0	0	2
1988	3	2	0	0	0	1	0	0	2
1989	0	0	0	0	0	1	0	0	2
1990	0	0	0	0	0	0	2	0	1
1991	1	1	0	0	0	0	0	1	0
Totals	14	9	2	2	1	2	7	1	11

3/23/92

Flightline Fire Incident Data - Combined Forces
Summary Statistics

Totals For Years 1977-91
Fire Incident Sizes
Small, Smoldering, No Fire
Total No. Of Incidents By Agent Type

Fire Type	Halon	CO2	PKP	AFFF	Water
Non Aircraft Fires	71	59	26	18	24
Engine Fires	136	16	3	10	3
Cold Starts	77	6	2	4	0
Electrical/Avionics	48	5	1	1	5
Wheel/Brake Fires	78	3	11	8	2
Fuel Spills	3	0	0	84	16
Fuel Leaks	22	0	0	2	0
Exposure Fires	1	0	0	1	0
Other Misc.	33	4	1	7	1
Totals	469	93	44	135	51

Flightline Fire Incident Data - Combined Forces
Summary Statistics

Totals For Years 1977-91
Fire Incident Sizes
Large Fires
Total No. Of Incidents By Agent Type

Fire Type	Halon	CO2	PKP	AFFF	Water
Non Aircraft Fires	3	2	1	7	1
Engine Fires	4	1	0	4	0
Cold Starts	1	0	0	1	0
Electrical/Avionics	1	0	0	1	0
Wheel/Brake Fires	0	0	0	0	1
Fuel Spills	1	0	0	1	0
Fuel Leaks	2	0	0	5	0
Exposure Fires	1	0	0	0	0
Other Misc.	2	0	0	8	1
Totals	15	3	1	27	3

APPENDIX C

MAINTENANCE DEPOT SURVEY REQUEST

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DEPARTMENT OF THE NAVY

NAVAL RESEARCH LABORATORY

WASHINGTON, D.C. 20375—5000

IN REPLY REFER TO:

3900
Ser 6180-3.1
JAN 16 1992

From: Commanding Officer, Naval Research Laboratory
To: Commander, Air Logistics Center, OC-ALC/LP
Tinker Air Force Base, OK 73145

Subj: REQUEST FOR AIRCRAFT FIRE DAMAGE AND CONTAMINATED ENGINE CLEAN-UP INFORMATION

Ref: (a) Montreal Protocol on Substances that Deplete the Ozone Layer, London Amendments, June 1990
(b) NRL Contract No. N00014-90-C-2330

Encl: (1) Aircraft Engine Fire Fighting Agent Contamination and Decontamination Information Request

1. In response to global concerns over chemicals and substances which deplete the earth's stratospheric ozone layer, the United States has signed the Montreal Protocol. The Protocol establishes schedules for the termination of over sixty ozone-depleting chemicals.

2. Halon 1211, a fire extinguishing agent, is among the sixty chemicals identified. Halon 1211 is currently the fire fighting "agent of choice" for aircraft engines, electronics and accessory fires. It has become the "agent of choice" for combatting such fires primarily due to its "clean agent" characteristics. The use of this agent produces few contaminants and requires little or no removal and decontamination efforts by aircraft engine rehabilitation facilities.

3. Canada has placed a total ban on all halon products used in fire fighting. The U.S. Air Force, U.S. Navy, and Federal Aviation Administration are now beginning to restrict the use of halon agents as they evaluate alternative, cost-effective "clean agents." Relevant factors being considered with respect to the alternate agents are:

a. The emerging candidate alternative agents are all currently in the $10.00/lb price range. This is considerably above the cost of other alternative agents currently in use, such as dry chemical agents, which run under $1.00/lb. As a result, efforts are underway to re-assess the need for a "clean agent" versus replacement of Halon 1211 with an existing agent.

b. A determination to use a "clean" versus a "dirty" agent will not be based solely on initial agent costs. The engine logistics system impact costs of using a "dirty agent may far surpass the initial cost savings noted above. This is because the ingestion of a "dirty" agent into a jet engine triggers a technical order requiring inspections and cleaning at base and depot levels.

Furthermore, engine out-of-commission pipeline factors and costs would be significantly impacted by increased engine depot reparable generations due to "dirty" agent use. All of these factors generate significant logistics costs that must be identified and included in the decision process to replace Halon 1211.

4. Other relevant data include the determination of: (1) what fire extinguishing agents are currently available, (2) what agents have been used in the past, and (3) what has been, or may be, the impact of these agents with regard to contamination and repair of aircraft engines and accessories.

a. As an example, dry chemical extinguishing agents, such as Purple K Powder (PKP), have long been known as major contaminants of aircraft engines. What is not known or readily available are the costs associated with the clean-up of engines contaminated by PKP or other "non-clean" agents. Accordingly, there is a need to acquire clean-up and repair cost information for PKP, AFFF, and halon-contaminated engines.

b. In addition, should a total ban on Halon 1211 be placed in effect before an alternative "clean agent" is found (e.g., such as the current Canadian Department of National Defense policy), it is envisioned that an immediate return to dry chemical agents, such as PKP for an initial attack flight-line fire extinguisher, would occur. If so, then an assessment/ evaluation of such a strategy on the impact of and increased requirements for aircraft engine pipeline spares is needed.

5. In an effort to answer these questions and to evaluate the need for development of new fire extinguishing agents, the U.S. Air Force, through reference (b), has tasked the Naval Research Laboratory (NRL) in Washington, D. C. and Hughes Associates, Inc. of Columbia, MD to obtain and analyze available field data and information from the appropriate Air Force and Navy Commands. Enclosure (1) provides guidelines for the information requested.

6. It is understood that it may be difficult to determine specific information regarding costs associated with decontamination and repair of individual engines. In the event that such information cannot be provided, generalized decontamination costs (e.g., annual number of engines contaminated by each type of extinguishment agent; average or total annual cost for each agent category) will be acceptable.

7. The names of facilities providing this information will not be disclosed in any reports. All references to file maintenance data,

costs, etc. will be reported in the context of general or average values only.

8. The points of contact are listed below:

Dr. Joseph T. Leonard
Code 6180
Naval Research Laboratory
Washington, D. C. 20375
(202) 767-3197 or 2002

Mr. Edward K. Budnick, P.E.
Hughes Associates, Inc.
6770 Oak Hall Lane, Suite 125
Columbia, MD 21045
(301) 596-2190

W. B. FOX
By direction

Copy (w/copy of encl (1)):
HQ AFCESA/RACF, Tyndall AFB (R. Vickers)

AIRCRAFT ENGINE FIRE FIGHTING AGENT
CONTAMINATION AND DECONTAMINATION INFORMATION REQUEST

GENERAL INFORMATION

(a) number of aircraft engines decontaminated each year at the depot level and at base level for the period 1980-1991 (by year and by specific extinguishing agent)

(b) estimated increase in maintenance costs at depot and base levels when dry chemical agents are used instead of Halon 1211 (by engine and by extinguishing agent)

(c) potential increase in pipeline spares (replacement engines)

NOTE: The request for estimated increase in pipeline spares (e.g., item b) refers to the number of additional spare engine requirements that may be generated due to increase decontamination/clean-up time and increase in depot reparable generations should a ban be placed on Halon 1211, resulting in an immediate return to PKP or other dry chemical agent.

DETAILED INCIDENT INFORMATION

(a) year

(b) engine type/aircraft type

(c) type of agent/contaminant (PKP, AFFF, Halon 1211)

(d) damage area (nacelle, engine, electronics, etc.)

(e) estimated down time for repairs (hours)

(f) replacement parts required (extent of repairs)

(g) estimated or average cost to tear down/rebuild (per agent basis)

(h) engine clean-up method used (water flush, dismantle, etc.)

(i) estimated down time for clean-up (hours)

(j) transportation costs

Encl (1) to NRL ltr
3900
Ser 6180-3.1

(k) total replacement/clean-up costs

(l) collateral clean-up costs for electronics or other systems

POINT OF CONTACT:

Information on incidents should be sent to:

Dr. Joseph T. Leonard
Code 6180
Naval Research Laboratory
Washington, D. C. 20375-5000

DEPARTMENT OF THE NAVY
NAVAL RESEARCH LABORATORY
WASHINGTON, D.C. 20375—5000

IN REPLY REFER TO:
3900
Ser 6180-3.2

JAN 16 1992

From: Commanding Officer, Naval Research Laboratory
To: Commander, Air Logistics Center, SA-ALC/LP, Kelly Air Force Base, TX 78241-2000

Subj: REQUEST FOR AIRCRAFT FIRE DAMAGE AND CONTAMINATED ENGINE CLEAN-UP INFORMATION

Ref: (a) Montreal Protocol on Substances that Deplete the Ozone Layer, London Amendments, June 1990
(b) NRL Contract No. N00014-90-C-2330

Encl: (1) Aircraft Engine Fire Fighting Agent Contamination and Decontamination Information Request

1. In response to global concerns over chemicals and substances which deplete the earth's stratospheric ozone layer, the United States has signed the Montreal Protocol. The Protocol establishes schedules for the termination of over sixty ozone-depleting chemicals.

2. Halon 1211, a fire extinguishing agent, is among the sixty chemicals identified. Halon 1211 is currently the fire fighting "agent of choice" for aircraft engines, electronics and accessory fires. It has become the "agent of choice" for combatting such fires primarily due to its "clean agent" characteristics. The use of this agent produces few contaminants and requires little or no removal and decontamination efforts by aircraft engine rehabilitation facilities.

3. Canada has placed a total ban on all halon products used in fire fighting. The U.S. Air Force, U.S. Navy, and Federal Aviation Administration are now beginning to restrict the use of halon agents as they evaluate alternative, cost-effective "clean agents." Relevant factors being considered with respect to the alternate agents are:

a. The emerging candidate alternative agents are all currently in the $10.00/lb price range. This is considerably above the cost of other alternative agents currently in use, such as dry chemical agents, which run under $1.00/lb. As a result, efforts are underway to re-assess the need for a "clean agent" versus replacement of Halon 1211 with an existing agent.

b. A determination to use a "clean" versus a "dirty" agent will not be based solely on initial agent costs. The engine logistics system impact costs of using a "dirty agent may far surpass the initial cost savings noted above. This is because the ingestion of a "dirty" agent into a jet engine triggers a technical order requiring inspections and cleaning at base and depot levels.

DEPARTMENT OF THE NAVY
NAVAL RESEARCH LABORATORY
WASHINGTON, D.C. 20375-5000

IN REPLY REFER TO:
3900
Ser 6180-3.3
JAN 1992

From: Commanding Officer, Naval Research Laboratory
To: Commanding Officer, Naval Aviation Depot (Code 31550), NAS North Island, San Diego, CA 92135-5522

Subj: REQUEST FOR AIRCRAFT FIRE DAMAGE AND CONTAMINATED ENGINE CLEAN-UP INFORMATION

Ref: (a) Montreal Protocol on Substances that Deplete the Ozone Layer, London Amendments, June 1990
(b) NRL Contract No. N00014-90-C-2330

Encl: (1) Aircraft Engine Fire Fighting Agent Contamination and Decontamination Information Request

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a. The emerging candidate alternative agents are all currently in the $10.00/lb price range. This is considerably above the cost of other alternative agents currently in use, such as dry chemical agents, which run under $1.00/lb. As a result, efforts are underway to re-assess the need for a "clean agent" versus replacement of Halon 1211 with an existing agent.

b. A determination to use a "clean" versus a "dirty" agent will not be based solely on initial agent costs. The engine logistics system impact costs of using a "dirty agent may far surpass the initial cost savings noted above. This is because the ingestion of a "dirty" agent into a jet engine triggers a technical order requiring inspections and cleaning at base and depot levels.

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DEPARTMENT OF THE NAVY

NAVAL RESEARCH LABORATORY

WASHINGTON, D.C. 20375-5000

IN REPLY REFER TO

3900
Ser 6180-3.4

From: Commanding Officer, Naval Research Laboratory
To: Commanding Officer, Naval Aviation Depot, MCAS Cherry Point, NC 28583

Subj: REQUEST FOR AIRCRAFT FIRE DAMAGE AND CONTAMINATED ENGINE CLEAN-UP INFORMATION

Ref: (a) Montreal Protocol on Substances that Deplete the Ozone Layer, London Amendments, June 1990
(b) NRL Contract No. N00014-90-C-2330

Encl: (1) Aircraft Engine Fire Fighting Agent Contamination and Decontamination Information Request

1. In response to global concerns over chemicals and substances which deplete the earth's stratospheric ozone layer, the United States has signed the Montreal Protocol. The Protocol establishes schedules for the termination of over sixty ozone-depleting chemicals.

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3. Canada has placed a total ban on all halon products used in fire fighting. The U.S. Air Force, U.S. Navy, and Federal Aviation Administration are now beginning to restrict the use of halon agents as they evaluate alternative, cost-effective "clean agents." Relevant factors being considered with respect to the alternate agents are:

a. The emerging candidate alternative agents are all currently in the $10.00/lb price range. This is considerably above the cost of other alternative agents currently in use, such as dry chemical agents, which run under $1.00/lb. As a result, efforts are underway to re-assess the need for a "clean agent" versus replacement of Halon 1211 with an existing agent.

b. A determination to use a "clean" versus a "dirty" agent will not be based solely on initial agent costs. The engine logistics system impact costs of using a "dirty agent may far surpass the initial cost savings noted above. This is because the ingestion of a "dirty" agent into a jet engine triggers a technical order requiring inspections and cleaning at base and depot levels.

DEPARTMENT OF THE NAVY
NAVAL RESEARCH LABORATORY
WASHINGTON, D.C. 20375—5000

IN REPLY REFER TO
3900
Ser 6180-3.5
JAN

From: Commanding Officer, Naval Research Laboratory
To: Commanding Officer, Naval Aviation Depot, NAS Alameda, Alameda, CA 94501

Subj: REQUEST FOR AIRCRAFT FIRE DAMAGE AND CONTAMINATED ENGINE CLEAN-UP INFORMATION

Ref: (a) Montreal Protocol on Substances that Deplete the Ozone Layer, London Amendments, June 1990
(b) NRL Contract No. N00014-90-C-2330

Encl: (1) Aircraft Engine Fire Fighting Agent Contamination and Decontamination Information Request

1. In response to global concerns over chemicals and substances which deplete the earth's stratospheric ozone layer, the United States has signed the Montreal Protocol. The Protocol establishes schedules for the termination of over sixty ozone-depleting chemicals.

2. Halon 1211, a fire extinguishing agent, is among the sixty chemicals identified. Halon 1211 is currently the fire fighting "agent of choice" for aircraft engines, electronics and accessory fires. It has become the "agent of choice" for combatting such fires primarily due to its "clean agent" characteristics. The use of this agent produces few contaminants and requires little or no removal and decontamination efforts by aircraft engine rehabilitation facilities.

3. Canada has placed a total ban on all halon products used in fire fighting. The U.S. Air Force, U.S. Navy, and Federal Aviation Administration are now beginning to restrict the use of halon agents as they evaluate alternative, cost-effective "clean agents." Relevant factors being considered with respect to the alternate agents are:

a. The emerging candidate alternative agents are all currently in the $10.00/lb price range. This is considerably above the cost of other alternative agents currently in use, such as dry chemical agents, which run under $1.00/lb. As a result, efforts are underway to re-assess the need for a "clean agent" versus replacement of Halon 1211 with an existing agent.

b. A determination to use a "clean" versus a "dirty" agent will not be based solely on initial agent costs. The engine logistics system impact costs of using a "dirty agent may far surpass the initial cost savings noted above. This is because the ingestion of a "dirty" agent into a jet engine triggers a technical order requiring inspections and cleaning at base and depot levels.

DEPARTMENT OF THE NAVY

NAVAL RESEARCH LABORATORY

WASHINGTON, D.C. 20375—5000

IN REPLY REFER TO

3900
Ser 6180-3.6
JAN 16 1992

From: Commanding Officer, Naval Research Laboratory
To: Commanding Officer, Naval Aviation Depot
NAS Norfolk, Norfolk, VA 23511

Subj: REQUEST FOR AIRCRAFT FIRE DAMAGE AND CONTAMINATED ENGINE CLEAN-UP INFORMATION

Ref: (a) Montreal Protocol on Substances that Deplete the Ozone Layer, London Amendments, June 1990
(b) NRL Contract No. N00014-90-C-2330

Encl: (1) Aircraft Engine Fire Fighting Agent Contamination and Decontamination Information Request

1. In response to global concerns over chemicals and substances which deplete the earth's stratospheric ozone layer, the United States has signed the Montreal Protocol. The Protocol establishes schedules for the termination of over sixty ozone-depleting chemicals.

2. Halon 1211, a fire extinguishing agent, is among the sixty chemicals identified. Halon 1211 is currently the fire fighting "agent of choice" for aircraft engines, electronics and accessory fires. It has become the "agent of choice" for combatting such fires primarily due to its "clean agent" characteristics. The use of this agent produces few contaminants and requires little or no removal and decontamination efforts by aircraft engine rehabilitation facilities.

3. Canada has placed a total ban on all halon products used in fire fighting. The U.S. Air Force, U.S. Navy, and Federal Aviation Administration are now beginning to restrict the use of halon agents as they evaluate alternative, cost-effective "clean agents." Relevant factors being considered with respect to the alternate agents are:

a. The emerging candidate alternative agents are all currently in the $10.00/lb price range. This is considerably above the cost of other alternative agents currently in use, such as dry chemical agents, which run under $1.00/lb. As a result, efforts are underway to re-assess the need for a "clean agent" versus replacement of Halon 1211 with an existing agent.

b. A determination to use a "clean" versus a "dirty" agent will not be based solely on initial agent costs. The engine logistics system impact costs of using a "dirty agent may far surpass the initial cost savings noted above. This is because the ingestion of a "dirty" agent into a jet engine triggers a technical order requiring inspections and cleaning at base and depot levels.

APPENDIX D

BASE LEVEL SURVEY REQUEST

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DEPARTMENT OF THE NAVY
NAVAL RESEARCH LABORATORY
WASHINGTON, D.C. 20375-5000

IN REPLY REFER TO:

3900
6180-291.2
29 April 1992

From: Commanding Officer, Naval Research Laboratory
To: DISTRIBUTION

Subj: REQUEST FOR AIRCRAFT ENGINE FIRE DAMAGE AND FIRE EXTINGUISHMENT AGENT CONTAMINATION INFORMATION

Ref: (a) Montreal Protocol on Substances that Deplete the Ozone Layer, London Amendments, June 1990

Encl: (1) Non-Navy Safety Center Reportable Fire Extinguishing Agent Incidents - Information Request

1. In response to global concerns over chemicals and substances which deplete the earth's stratospheric ozone layer, the United States has signed the Montreal Protocol. The Protocol establishes schedules for the termination of over sixty ozone-depleting chemicals (reference (a)).

2. Halon 1211, a fire extinguishing agent, is among the sixty chemicals identified. Halon 1211 is currently the fire fighting "agent for choice" for aircraft engines, electronics and accessory fires primarily due to its "clean agent" characteristics. The use of this agent produces few contaminants and requires minor or no removal and decontamination efforts by aircraft engine rehabilitation facilities.

3. Canada has placed a total ban on all halon products used in fire fighting. The U.S. Air Force, U.S. Navy, and Federal Aviation Administration are now beginning to restrict the use of halon agents as they evaluate alternative, cost-effective "clean agents." Relevant factors being considered with respect to the alternate agents are:

a. The emerging candidate alternative agents are all currently in the \$10.00/lb price range. This is considerably above the cost of existing agents such as dry chemical agents which run under \$1.00/lb. As a result, efforts are underway to reassess the need for a "clean agent" versus replacement of Halon 1211 with an existing agent, which would require some post-fire clean-up procedure.

b. However, a determination to use a "clean" versus a "dirty" agent will not be based solely on initial agent costs. The engine logistics system impact costs of using a "dirty" agent may far surpass the initial cost savings noted above. This is because the ingestion of a "dirty" agent into a jet engine triggers technical order required inspections and cleaning at base and depot levels. Furthermore, engine out-of-commission pipeline

Subj: REQUEST FOR AIRCRAFT ENGINE FIRE DAMAGE AND FIRE EXTINGUISHMENT AGENT CONTAMINATION INFORMATION

costs, which must be identified and included in the decision process, could be significantly impacted by increased engine depot reparable generations due to "dirty" agent use. All of these factors generate significant logistics concerns in considering the replacement of Halon 1211.

4. In an effort to answer these questions and to evaluate the need for development of new fire extinguishing agents, the U.S. Air Force has tasked the Naval Research Laboratory (NRL) in Washington, DC and its contractor, Hughes Associates, Inc. of Columbia, MD, to obtain and analyze available field data and information from appropriate Air Force and Navy Commands. Information from the Naval Safety Center along with the U.S. Air Force Logistics Centers and Naval Aviation Repair Depots is presently being requested through separate correspondence. Enclosure (1) provides guidelines for information requested from U.S. Air Force and U.S. Navy Fire Service, Aircraft Squadrons, and Aircraft Intermediate Maintenance Organizations at the facility or base level.

5. It is expected the Naval Safety Center will provide fire damage monetary loss and extinguishing agent data from reports submitted by the services in accordance with existing guidelines. There are, however, non-reportable data that may be available at aircraft squadrons, aircraft maintenance activities, and aircraft fire departments which are germane to the analysis effort. Specifically, it is essential that incidents be identified where fire extinguishing agents were applied on aircraft engine fires but little or no fire damage actually resulted, and thus no formal fire loss damage report was submitted. These data are important because of the maintenance impact caused by the type of fire extinguishing agent applied.

6. It is requested that Base Fire Officials, in consort with local aircraft squadrons and aircraft maintenance departments, provide whatever data are available regarding non-reportable incidents where fire extinguishing agents were applied to aircraft and aircraft engines or accessories. For each incident, please document the information requested in enclosure (1). Please go back as far as 1985 where possible. If historical records are not available but there is a personal experience within the staff of the organization, then provide your best estimates of an average annual number of incidents and types of incidents experienced. In this case, a narrative response will suffice. One indicator of a no-fire damage incident would be when maintenance personnel bring, or report, a

3900
6180-291.2
29 April 1992

Subj: REQUEST FOR AIRCRAFT ENGINE FIRE DAMAGE AND FIRE EXTINGUISHMENT AGENT CONTAMINATION INFORMATION

Halon 1211 flightline fire extinguisher for refill and no corresponding fire incident is reported because the aircraft, or accessory was not "downed" for repair due to fire damage. However, some minor maintenance impact may have been experienced.

7. NRL and Hughes Associates, Inc. will maintain confidentially of all information received. All references will be reported in the context of general and average numbers of incidents and will not be reported on an individual base or facility basis. NRL requests the information provided by enclosure (1) be returned not later than 30 May 1992. Your best effort in endeavoring to meet our "short fuse" request is appreciated.

8. The point of contact and address for responses to this study is Dr. Joseph T. Leonard, Code 6180, Naval Research Laboratory, Washington, D. C. 20375-5000, (202) 767-3197.

WILLIAM B. FOX
By direction

Copy to:
HQ AFCESA/RACF, Tyndall AFB (R. Vickers)
Hughes Associates, Inc., Columbia, MD

NON-NAVY SAFETY CENTER REPORTABLE FIRE EXTINGUISHING AGENT INCIDENTS

INFORMATION REQUEST

1. For the years 1985 through 1991, please detail the following information (by year of occurrence) on aircraft related fires and extinguishing agent for which you were not required to file a Naval Safety Center fire loss report.

NOTE: Please include flight line fires extinguished by personnel attached to various squadrons and aircraft maintenance organizations at your base or facility. This information is very important to this study.

(a) Date: Month/Year
(b) Type of Aircraft
(c) Fire Area: Nacelle, Engine, Electronics, Wheel, Fuel Tank, Etc.
(d) Was fire actually observed or suspected (smoke etc.)?
(e) Type of extinguishing agent(s) used: Halon, PKP, CO_2, AFFF
(f) Amount of agent expended?
(g) Agent expended by Fire Department, Squadron, or Maintenance Personnel

2. Please provide a contact point and telephone number in the event clarification of data provided may be required.

3. Fire Department Point of Contact for this report:

Name ______________________

Title/Code Number ______________________

Address ______________________

4. Telephone #: Autovon ______________________
Commercial ______________________

5. Aircraft Maintenance Organization Point of Contact for this report:

Name ______________________

Title/Code Number ______________________

Address ______________________

6. Telephone #: Autovon ______________________
Commercial ______________________

Encl (1) to NRL ltr
3900
6180-291.2

DISTRIBUTION:

LIST OF U.S. NAVY AND U.S. MARINE CORPS FIRE DEPARTMENTS TO BE SURVEYED

Fire Chief
Code 18
Bldg N-26, Room 162
Naval Air Station
Norfolk, VA 23511-6000

Fire Chief
Code 309
Naval Air Station, Oceana
Virginia Beach, VA 23460-5120

Crash Fire Rescue Officer
Air Operations, Crash Crew
Stop 22
Cherry Point, NC 28533-5001

Fire Chief
Code 309, Air Operations Department
Naval Air Station
Cecil Field, FL 32215

Crash Fire Rescue Officer
Marine Corps Air Station
Beaufort, SC 29902

Fire Chief
Code 309, Box 7
Naval Air Station
Jacksonville, FL 32212

Fire Chief
Naval Air Station
Key West, FL 33040

Fire Chief
Naval Air Station, Whiting Field
Milton, FL 32570

Fire Chief
Building 21
Naval Air Station
Pensacola, FL 32508

Fire Chief
Building 1742
Naval Air Station
Corpus, Christi, TX 28419

Fire Chief
Building 2142
Naval Air Station, Chase Field
Beeville, TX 78103

Fire Chief
Building 776
Naval Air Station
Kingsville, TX 78363

Fire Chief
Federal Fire Department San Diego
Naval Air Station, North Island (Code 80)
San Diego, CA 92135

Crash Fire Rescue Officer
Marine Corps Air Station (H)
Santa Ana, CA 92709

DISTRIBUTION: (continued)

LIST OF U.S. AIR FORCE FIRE DEPARTMENTS TO BE SURVEYED

36 CES/DEF
APO NY 09132

48 CES/DEF
APO NY 09179

377 CES/DEF
APO NY 09094-5000

27 CES/DEF
Cannon AFB, NY 88101

833 CES/DEF
Holloman AFB, NM 88330

1 CES/DEF
Langley AFB, VA 23665

89 CES/DEF
Andrews AFB, MD 20331-5000

443 CES/DEF
Altus AFB, OK 73523-5436

375 CES/DEF
Scott AFB, IL 62225-5045

2 CES/DEF
Barksdale, AFB, LA 71110

96 CES/DEF
Dyess AFB, TX 79607

857 CES/DEF
Minot AFB, ND 58705

834 CES/DEF
Hurlburt Field, FL 32544-5000

663 CES/DEF
APO SF 96334

8 CES/DEF
APO SF 96264

18 CES/DEF
APO SF 96239

117 TRW/DEF
Birmingham ANGB, AL 35217-0198

125 FIG/DEF
Jacksonville, FL 32229-0018

151 AREFG/DEF
Salt Lake City, UT 84116-2999

3202 CES/DEF
Eglin AFB, FL 32542-5000

12 CES/DEF
Randolph AFB, TX 78150-5001

323 CES/DEF
Mather AFB, CA 95655-5000

2853 CES/DEF
Robins AFB, GA 31098-5000

2750 CES/DEF
Wright-Patterson AFB, OH 45433-5000

2849 CES/DEF
Hill AFB, UT 84056-5000

DISTRIBUTION: (continued)

Fire Chief
Naval Air Station, Memphis
Building South (84)
Millington, TN 38054

Crash Fire Rescue Officer
Detachment MABS-11
Marine Corps Air Ground Center
Twentynine Palms, CA 92278

Crash Fire Rescue Officer
Marine Corps Air Station
Yuma, AZ 85369-5000

Fire Chief
Naval Air Station
Moffett Field, CA 94035

Fire Chief
Naval Air Station
Fallon, NV 89406

Fire Chief
Naval Air Station
Alameda, CA 94501

Crash Fire Rescue Officer
Marine Corps Air Station (H)
Tustin, CA 92710

Fire Chief
Code 242
Naval Weapons Center
China Lake, CA 93555

Fire Chief
Naval Air Station
Lemoore, CA 93245

Fire Chief
Code AOF
Naval Air Station
Building 2526
Whidbey Island
Oak Harbor, WA 98278

Fire Chief
Naval Air Station
Patuxent River, MD 20670-5409

Fire Chief
Naval Air Station, Code 45
Box 6, PSC 1003
Keflavik, Iceland
FPO AE 09728-0306